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THE INFLUENCE OF A LOWER HEATED TUBE ON
NUCLEATE POOL BOILING
FROM A HORIZONTAL TUBE

by

Lannie R. Lake

June 1992

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<p>Nucleate pool boiling is an essential part of the vast cooling systems today's combatant ship combat systems are dependent upon. Understanding the mechanisms that influence heat transfer in tube bundles in a liquid pool is the stepping stone for improving these cooling systems. This thesis attempts to bridge the gap between single tube performance and bundle performance by studying the effect of a lower heated tube on the heat transfer from an upper tube in a simple two tube bundle. This study concludes that a nucleating lower tube (regardless of the spacings tested between tubes) has a significant positive (i.e. improvement of heat transfer) influence upon upper tube. This is especially evident for a smooth tube where any hysteresis effects are completely eliminated when the lower tube nucleates at a heat flux of 10 kW/m^2 or greater. Furthermore, the only influence for the pitch-to-diameter ratios tested was at the highest heat fluxes for the smooth tubes where a p/d of 1.8 was found to give the maximum heat transfer. No such maximum was obtained for the enhanced tubes.</p>					
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The Influence of a Lower Heated Tube on Nucleate Pool Boiling
from a Horizontal Tube

by

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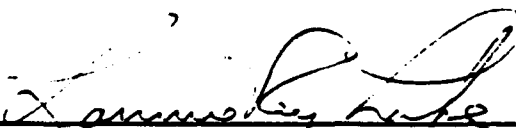
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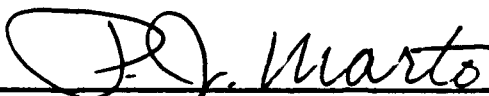
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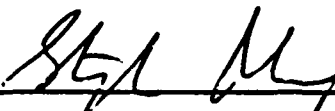


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ABSTRACT

Nucleate pool boiling is an essential part of the vast cooling systems today's combatant ship combat systems are dependent upon. Understanding the mechanisms that influence heat transfer in tube bundles in a liquid pool is the stepping stone for improving these cooling systems. This thesis attempts to bridge the gap between single tube performance and bundle performance by studying the effect of a lower heated tube on the heat transfer from an upper tube in a simple two tube bundle. This study concludes that a nucleating lower tube (regardless of the spacings tested between tubes) has a significant positive (i.e. improvement of heat transfer) influence upon upper tube. This is especially evident for a smooth tube where any hysteresis effects are completely eliminated when the lower tube nucleates at a heat flux of 10 kW/m^2 or greater. Furthermore, the only influence for the pitch-to-diameter ratios tested was at the highest heat fluxes for the smooth tubes where a p/d of 1.8 was found to give the maximum heat transfer. No such maximum was obtained for the enhanced tubes.

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NOMENCLATURE

Note that properties and measured parameters of the lower (auxiliary) tube are differentiated from the upper tube with A added to that property or parameter (i.e. ACp is the specific heat of the lower (auxiliary) tube). Though this may cause confusion with area dimensions, this nomenclature is preserved because it is used within programs SETUP72 (appendix C) and DRP72 (appendix D). Note also that like tubes were used in upper and lower positions such that spatial dimensions are the same and are not differentiated between tubes.

A	area
Ab	tube outside surface area of active boiling section
Ac	cross sectional area of the tube
Cp	specific heat
ACp	specific heat of lower (auxiliary) tube
D	diameter
Di	tube inside diameter
Do	tube outside diameter
D1	diameter of the position of the thermocouple
D2	outer diameter of the boiling tube
g	gravitational acceleration
h	heat transfer coefficient
Ah	heat transfer coefficient of lower tube
I	current
AI	current for lower tube
Is	output voltage of AC current sensor
AI _s	output voltage of AC current sensor for lower tube
k	thermal conductivity of liquid
Ak	thermal conductivity of liquid associated with lower tube
kc	thermal conductivity of copper
L	active boiling tube length
Lu	non-boiling tube length

Nu	Nusselt number
p	tube outside wall perimeter
Pr	Prandtl number
APr	Prandtl number associated with lower tube
Q	heat transfer rate from boiling surface
AQ	heat transfer rate from boiling surface of lower tube
Q_f	heat transfer rate through one non-boiling end
AQ_f	heat transfer rate through one non-boiling end of lower tube
Q_h	heat transfer rate from cartridge heater
AQ_h	heat transfer rate from lower tube cartridge heater
q''	heat flux
Aq''	heat flux from lower tube
Ra	Rayleigh number
T	temperature
T_{avg}	average wall temperature at the thermocouple location
AT_{avg}	average wall temperature at the thermocouple location for the lower tube
T_c	critical temperature
T_f	film temperature
AT_f	film temperature of fluid associated with lower tube
T_n	temperature of the thermocouple location
T_{sat}	saturation temperature
T_{wo}	outer wall temperature of the boiling test tube
AT_{wo}	outer wall temperature of the lower tube
V	voltage across the cartridge heater
AV	voltage across the cartridge heater for the lower tube
V_s	voltage output by AC-DC true RMS converter
AV_s	voltage output by AC-DC true RMS converter for lower tube
α	thermal diffusivity
$A\alpha$	thermal diffusivity associated with lower tube
β	volumetric thermal expansion coefficient
$\Lambda\beta$	volumetric thermal expansion coefficient associated with lower tube

δ	uncertainty in measurement and calibration
θ	superheat
$A\theta$	superheat associated with lower tube
μ	dynamic viscosity
$A\mu$	dynamic viscosity associated with lower tube
ν	kinematic viscosity
$A\nu$	kinematic viscosity associated with lower tube
ρ	density
$A\rho$	density associated with lower tube

I. INTRODUCTION

As the United States continues to struggle with the dilemma of increasing requirements for CFC's, while at the same time joining the world in concern over ozone depletion, the exigency of finding replacements for the Navy's high ozone depletion potential fluids is of the highest order. The urgency of this search was made more pressing by the reduction of the time allowed (ordered by President Bush) to meet Montreal Protocol deadlines to purge use of CFC refrigerants. A particularly damaging fluid is R-114, used primarily in centrifugal chilled-water air-conditioning plants onboard ships. In order to best determine a short term or "drop in" replacement, data of R-114 nucleate pool boiling characteristics is required for comparison. The literature provides many studies of single tubes in nucleate pool boiling; however, studies of multiple tubes are more scarce. Most studies of multiple tubes with varied tube spacings were conducted in a manner to simulate a bundle, i.e. all tubes in the pool were studied with the same applied heat flux. There is little work in the literature on the effect of a lower heated tube on the heat transfer from an upper tube (i.e. a simple bundle) and none with R-114. This type of data would begin to bridge the gap between single tube nucleate pool boiling and bundle effects, and would complement the search for a suitable replacement for R-114.

To increase the available data for comparison with possible replacement refrigerants, and to further investigate the effect of tube spacing, the following objectives of this thesis were established:

1. Modify the existing single tube pool boiling apparatus to accommodate a simple two tube bundle, including program modifications to facilitate instrumenting the second tube.
2. Operate the apparatus to prove repeatability with single tube data.
3. Obtain convection and boiling data over several tube pitches and heat flux settings for both a smooth tube and an enhanced tube.

Of particular note is that this study was designed as a follow up to the single tube work of Sugiyama [Ref. 1]. The format of this study, including the correlations and programs used, are adaptations from Sugiyama's work in order to make the results directly comparable.

II. MECHANISMS

A. SINGLE TUBE BEHAVIOR

Experimental heat transfer behavior has been fairly well predicted from single smooth cylindrical tubes in an infinite pool for the natural convection region by Churchill and Chu [Ref. 2] and Churchill and Usagi [Ref. 3] and, to a lesser degree, for the boiling region by Rohsenow [Ref. 4] and Stephan and Abdelsalam [Ref. 5]. Single enhanced tubes have also been widely studied with nucleate pool boiling enhancements ranging up to 15 times the performance of smooth tubes. The largest enhancements have been obtained for re-entrant cavity surfaces as reported by Yilmaz and Westwater [Ref. 6], Marto and Lepere [Ref. 7], and Wanniarachchi *et al.* [Refs. 8, 9]. In these studies, enhancements were largely attributable to increased surface area in the convection regime, and to stable vapor sites (i.e. vapor trapped in re-entrant cavities), which provided a high density of active nucleation sites at relatively low values of wall superheat in the boiling regime. However, to date, no comprehensive model or correlation has been presented which can predict such enhancements (Thome addresses this in discussion of nucleate pool boiling correlations [Ref. 10]).

B. MULTIPLE TUBE BEHAVIOR

The behavior of a particular tube in a multiple tube environment will be greatly influenced by its neighboring tubes. In both the natural convection and nucleate boiling regimes, fluid heated by a lower tube will rise due to buoyant forces, and an upper tube will tend to be affected, specifically by the heated liquid plume in the convection regime and by the bubble plume in the boiling regime. Also in a bundle the lower tubes may impart a 'drag' on the fluid as it traverses the bundle affecting the fluid reaching an upper tube. The lower tube, because it is not impacted by a similar plume, can be assumed to behave as a single tube in a pool. However, if a bundle is in a confined pool, it may be the case that strong recirculation patterns cause an upper tube, in turn, to affect the heat transfer behavior from a lower tube.

The effect of a lower tube on an upper tube has been studied by Sparrow and Niethammer [Ref. 11] and Marsters [Ref. 12] in the convection region (using air), and by Fujita *et al.* [Ref. 13] and by Hahne, Qiu-Rong and Windisch [Ref. 14] in the nucleate boiling region (using refrigerants). These effects are primarily the result of two contradictory influences, increased fluid velocity in the convection or boiling bubble

plume and increased fluid temperature. In the natural convection region, fluid heated by the lower tube will have a velocity due to buoyant forces when it arrives at the upper tube. In effect the upper tube is no longer in a true natural convection regime but is beginning to experience some forced convection (i.e. mixed convection), thus increasing its heat transfer coefficient. At the same time the heat from the lower tube that causes this buoyant plume to rise has increased the temperature of that fluid within the plume, thereby decreasing the temperature difference between the upper tube and the fluid and decreasing the heat transfer capability. Two of the parameters affecting the strength of these influences are tube separation and the heat flux setting of the lower tube. The temperature of the fluid within the buoyant plume arriving at the top tube will be slightly lower than its temperature when it left the lower tube due to convection to the surrounding fluid. This drop in temperature will tend to increase with increasing tube separation, thereby increasing the ΔT between the upper tube and plume. This implies that the upper tube's heat transfer capability at large pitch may be expected to improve over that at small pitch. In addition, with Sugiyama's [Ref. 1] single tube work, convection plumes were turbulent (Grashof numbers were greater than 10^9), implying that plume velocity will not change with tube separation. However in reality at high enough Grashof numbers, the formation of eddies and other currents in the pool would tend to cause a decrease in the plume fluid velocity at the upper tube and thereby a decrease in the heat transfer coefficient over that of a smaller pitch. These two effects, increasing ΔT with increasing pitch and decreasing heat transfer coefficient at large pitch suggest that an optimum pitch is possible. These influences are confirmed by Sparrow and Niethammer's work with air [Ref. 11] and by Marsters [Ref. 12] with air, for which they found a dependence on the x-based Grashof number (based on the position of the tubes) for the heat transfer from the upper tube.

In the nucleate boiling regime, the above two effects are also important. The fluid entrained in the bubble plume from the lower tube (and the bubbles themselves) impinge upon the upper tube at a much higher velocity than with a convection plume (due to greater buoyant forces associated with the bubbles). This greater velocity of the plume and the bubbles would have the same influence as in convection above and may be sufficient to strip the thermal boundary layer from the upper tube, thereby lowering heat transfer resistance and increasing the heat transfer coefficient. Enhancements due to the impingement of plume and bubbles is most significant at lower heat fluxes when active nucleation site density on the upper tube is low. This provides more 'contact' area between the upper tube and the rising fluid/bubble mixture. As flux is increased on the

upper tube, the active nucleation site density also increases. At high heat fluxes, boiling is so vigorous that the rising fluid is prevented from gaining any appreciable 'contact' with the upper tube. Heat transfer coefficients may then be expected to increase with increasing tube spacing (as in the convection regime) with a possible optimum. However, enhancement due to the lower tube may be expected to decrease when high heat fluxes are applied to the upper tube. The trends of these influences were verified by Fujita *et al.* [Ref. 13] and Hahne *et al.* [Ref. 14].

An additional influence in the boiling regime may be the effect of 'seeding' from the lower tube when it is boiling. At low and medium heat fluxes on the upper tube (active nucleation site density is low), vapor bubbles from the lower tube may impinge and influence enter an inactive cavity on the bottom half of the upper tube. This may prompt an otherwise inactive site to become active earlier than it would have done for a single tube. This influence would also be more effective at low fluxes (low site density) on the upper tube. At higher fluxes, the number of active sites is higher and the probability of an added site becoming active due to this seeding process is significantly lower.

III. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. GENERAL DESCRIPTION

The apparatus used is an adaptation of the apparatus used by Karasabun [Ref. 14: pp 24-41], Reilly [Ref. 15 : pp. 30-44], and Sugiyama [Ref. 1: pp. 8-32] in previous studies of pool boiling of R-114/oil mixtures from single tubes. Karasabun provides complete details of the original configuration of the apparatus. The current apparatus was essentially that used by Sugiyama for single tubes with modifications made to accommodate two tubes in the evaporator. Additionally, the original R-12 cooling system was operated in conjunction with a R-502 system to increase cooling capacity for the increased heat load of two tube operation. An additional smooth and high flux tube were manufactured in order that both a smooth and an enhanced tube set could be studied in the two tube configuration. The unused auxiliary variac power supply was employed as the power supply for the second tube. A two tube data reduction program DRP72 was developed by adapting Sugiyama's single tube data reduction program DRP7.

The apparatus is labeled on a general schematic in Figure 1 and consists essentially of seven components:

1. An evaporator, a boiling vessel assembled using a Pyrex-glass tee with aluminum/teflon endplates.
2. A condenser, assembled using a similar Pyrex-glass tee with aluminum endplates.
3. A reservoir for R-114 liquid storage.
4. A cooling subsystem composed of an 1/2 ton R-502 and a 1/4 ton R-12 refrigeration plant, a 30 gallon water/ethylene glycol sump, and two positive displacement pumps.
5. A vacuum pump.
6. A data acquisition and instrumentation system.
7. An aluminum framework with plexiglass siding within which components 1-3 were housed.

The apparatus was designed for reflux operation. Vapor generated in the evaporator followed a path through an aluminum L-shaped pipe to the condenser. R-114 condensate then returned to the evaporator via copper tubing by gravity. The water/ethylene glycol sump of the cooling subsystem was maintained between -10 and -17 °C. This was accomplished using two separate cooling schemes. The R-502 refrigeration plant cooled the mixture via a counter current heat exchanger through which the

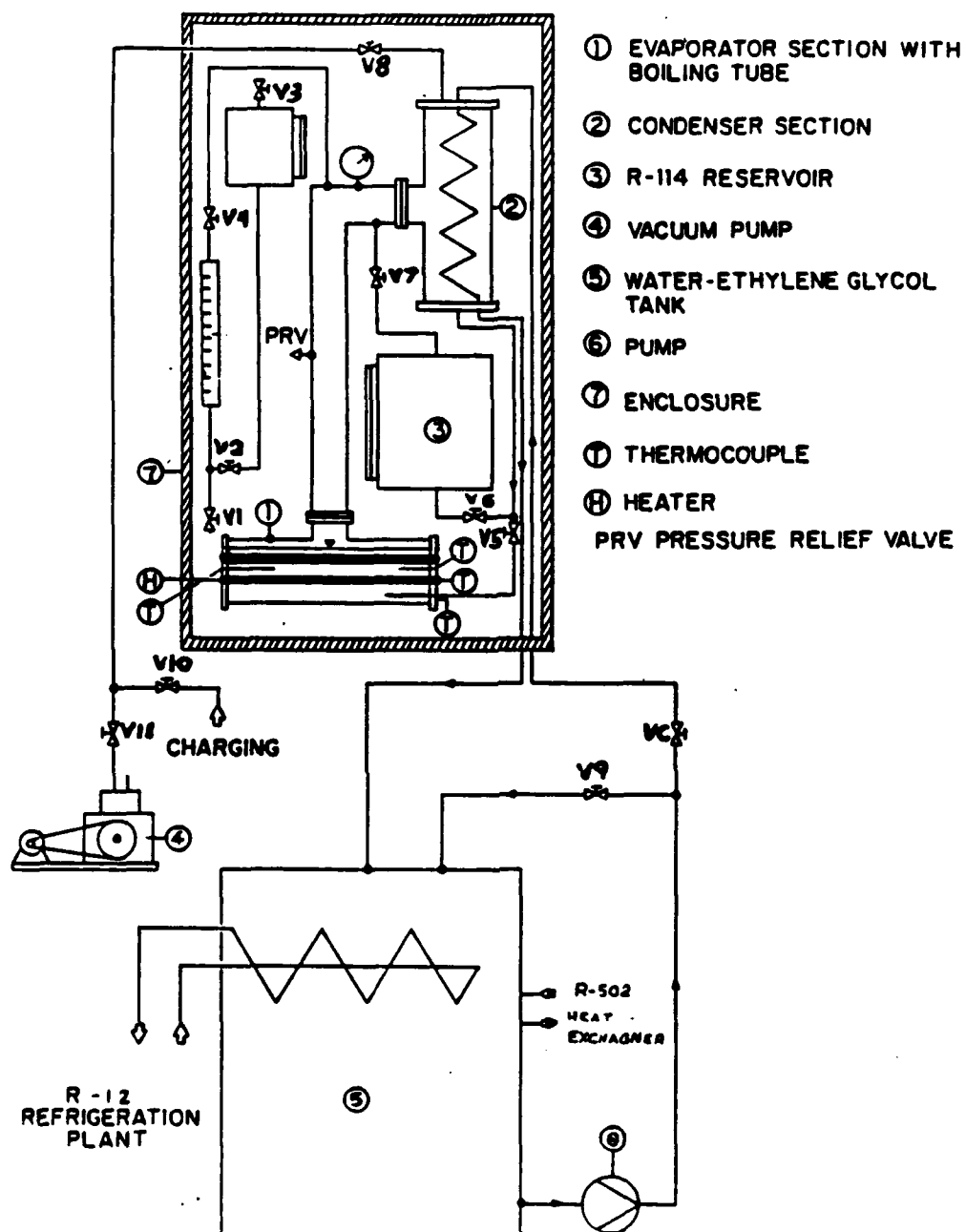


Figure 1. Schematic of Apparatus

water/ethylene glycol mixture was circulated by an 8-gpm turbine-type pump. The R-12 refrigeration plant cooled via an evaporator, constructed of coiled copper tubing, located directly within the sump. The second 8-gpm turbine-type pump circulated the mixture from the sump through copper condensing coils within the condenser via a control valve (VC, see Figure 1), and then returned to the sump.

An alternate mode of operation was used to evacuate the boiler to facilitate tube change out. R-114 was boiled off from the evaporator and condensed as before, but in this case R-114 condensate was directed to the reservoir (by changing certain valves), instead of returning to the evaporator. Once tube changeout was completed the evaporator was simply refilled from the reservoir by gravity.

This study was devoted to pure R-114. In order to ensure that no oil could intrude into the system, the oil path between the oil reservoir and the evaporator (used for R-114/oil mixture tests) was removed and the access to the evaporator plugged. The major components of the oil subsystem (reservoir and graduated cylinder) were left intact for use in future studies.

B. BOILING TEST SECTION

1. Evaporator

The evaporator consisted of a Corning Pyrex-glass tee (3 in. nominal interior diameter) with aluminum endplates. The endplates were coupled to the glass tee by Corning cast iron removable flanges. The glass vessel was mounted horizontally with the side-arm of the tee vertical. The major modification in adapting the apparatus from a single tube to two tubes was to the evaporator endplates. New endplates were manufactured with thermocouple and liquid fill/return penetrations moved to the periphery and a three inch hole centered on the axis of the evaporator. Teflon inserts were manufactured to fit tightly into this hole with varied spacings for the two test tubes. Though the teflon endplates could be rotated to accommodate a variety of tube geometries, only vertical spacing was addressed in this study (i.e. one tube vertically below the other). The addition of another tube to the evaporator also required the liquid level to be raised. The new liquid level was only 10 mm from the top of the Pyrex glass tee and 10 mm above the top of the upper tube (note that for all spacings the upper tube was fixed in position relative to the evaporator and the lower tube was varied). This severely reduced the vapor path between the liquid surface and the top of the evaporator to the exit tee. A comparison of the modified and previous apparatus liquid levels, tube positions and fittings is shown in Figure 2.

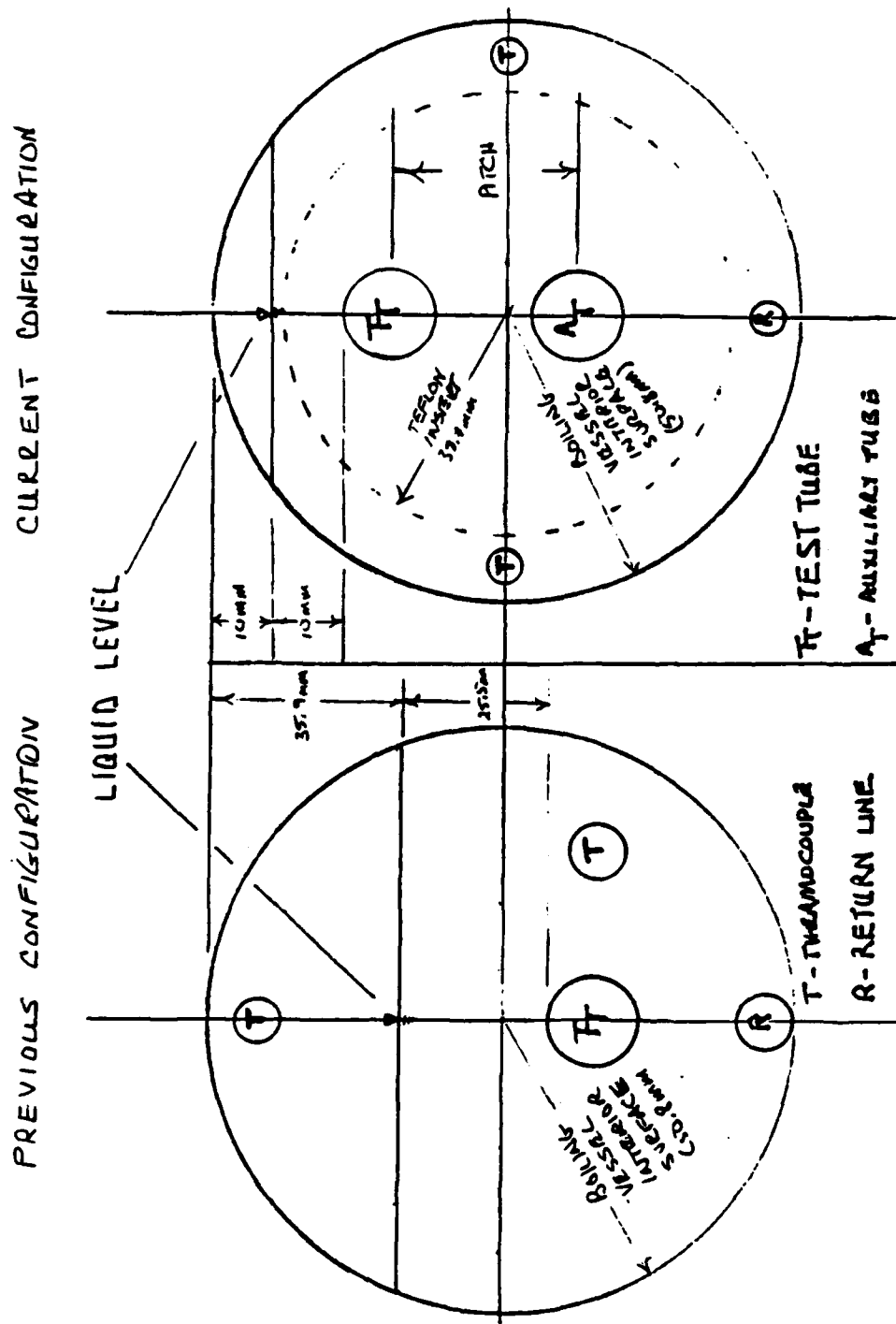


Figure 2. Comparison of Modified and Previous Apparatus

Pyrex-glass was used for both the evaporator and condenser due to its greater strength compared to ordinary glass. It was necessary for the apparatus to withstand pressure differences (between apparatus interior and atmospheric) of up to 20 psig due to possible R-114 vapor pressures at high room temperatures during summer months. In addition, a glass vessel provided several other advantages over a metal one:

- The transparent vessel allowed easy visual observation and videotaping of the boiling phenomena occurring inside.
- The smooth interior surface minimized any nucleate boiling at this inner surface.

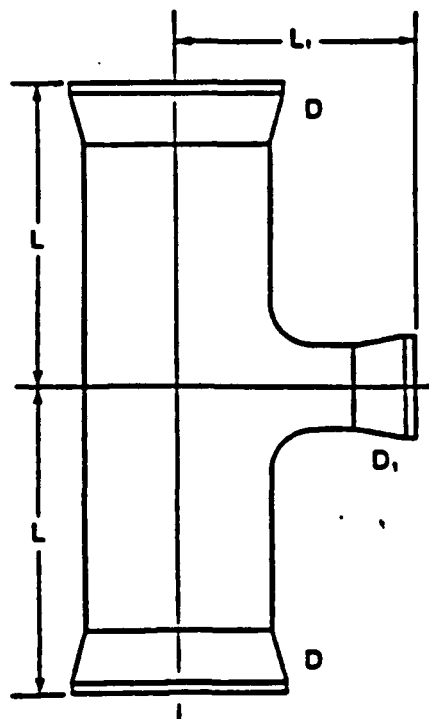
A relief valve (set at 20 psig) was mounted in the aluminum piping between the evaporator and condenser to prevent the safe working pressure (30 psig) of the Pyrex glass tee from being exceeded. A sketch of the glass tee and the cast iron flanges is shown in Figure 3. A sketch of an endplate and a teflon block insert is shown in Figure 4.

2. Test Tubes

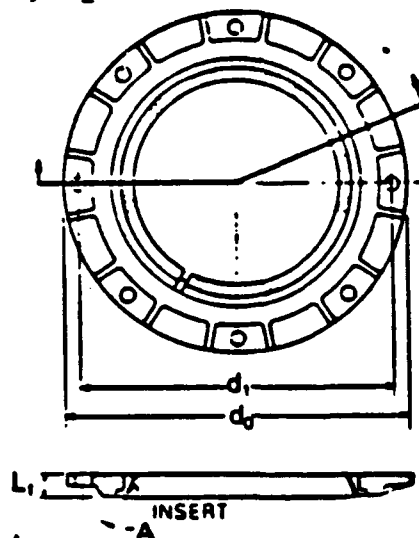
A general schematic of the tubes is shown in Figure 5. The tubes protruded through (and were supported by) the teflon inserts in the endplates of the evaporator. The teflon inserts were sealed by viton O-rings, two O-rings between the teflon inserts and each tube, and one O-ring between the insert and the aluminum endplate.

Two types of tube were used, a smooth hard-copper tube and a High Flux porous-coated tube. The tubes were heated via a stainless steel, 240-volt, 1000-watt (nominal), Watlow Firerod cartridge heater, 6.35 mm in outer diameter, 203.2 mm in actual length with an actual heated length of 190 mm. The heater was tightly inserted into a copper sleeve, which functioned as a mounting device for the thermocouples. The sleeve was then inserted in the tube. Both the heater and the sleeve were tinned with soft solder prior to being inserted into the tube and the whole assembly heated in a furnace to bond the assembly together. This minimized thermal resistance and provided a uniform heat flux along the length of the tube. The heater and sleeve were inserted such that the central 190 mm were heated radially by the heater. This was taken as the active boiling length. A correction was applied for the heat lost from the two ends of the tube in the pool.

The tubes were each instrumented with eight thermocouples soldered into channels which were machined in the outer surface of the sleeve. These thermocouples were located at various axial and circumferential locations as shown in Figure 6. The



a) Corning Pyrex Glass Evaporator ($D \times D_1 = 402 \times 51$ mm,
 $L = 178$ mm, $L_1 = 127$ mm)



b) Cast Iron Flange and Gasket ($d_1 = 190$ mm, $d_0 = 210$ mm,
 $L_1 = 14$ mm, $A = 21^\circ$)

Figure 3. Sketch of Pyrex Glass Vessels and Flanges

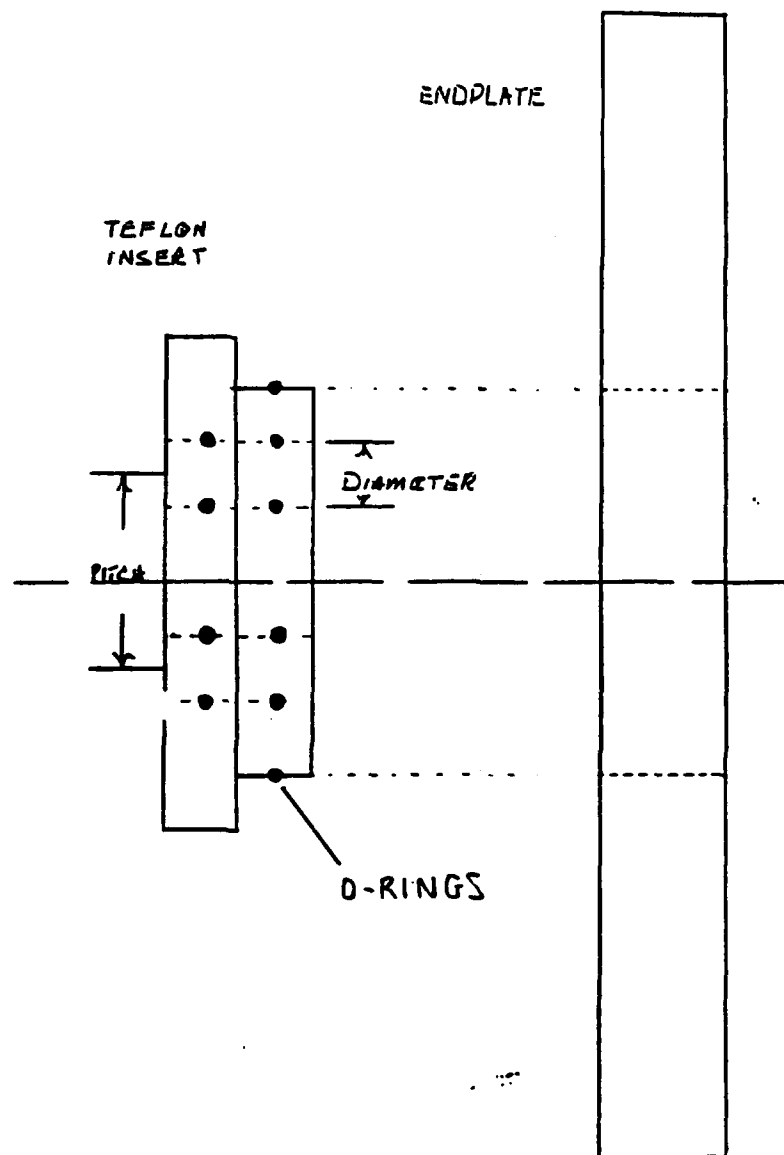


Figure 4. Sketch of Endplates and Teflon Inserts

thermocouple grooves were axially machined to the nearest end of the sleeve to provide a path for the thermocouple leads. Type-T Teflon coated copper-constantan thermocouple wire was used both in the tubes and throughout the apparatus. Dimensions and for the tubes are given in Table 1.

Table 1. TEST TUBE DIMENSIONS

Tube Type	D1(mm)	D2(mm)	Di(mm)	Do(mm)	L(mm)	Lu(mm)	Kwall (W/m • K)
Smooth	12.44	15.88	12.70	15.88	190.0	76.20	344
High Flux (95/5 Copper-Nickel)	12.95	15.82	13.20	15.82	190.0	76.20	45

C. CONDENSER SECTION

The condenser was assembled similarly to the evaporator. The same size Pyrex-glass tee was used as the main vessel with aluminum endplates. The glass vessel was mounted vertically with side-arm tee horizontal to receive the R-114 vapor. A helical condensing coil made of 9.5 mm copper tubing was inserted in the Pyrex glass tee. Swagelock fittings were used to connect the condenser coil to the coolant tubing through the condenser endplates. The coil was fabricated to an approximate outside diameter of 76 mm, providing an active condensation length of approximately 4.5 m.

The vacuum pump was connected to the top of the condenser via two isolation valves to remove any noncondensable gases that collect there. A tubing connection was placed in the bottom endplate of the condenser to enable R-114 condensate to drain back to the evaporator by gravity. Valve and tubing lineup was such that condensate could also be directed back to the R-114 reservoir. The condenser was connected to the evaporator by an L shaped aluminum tube two inches in diameter. The pressure relief valve, mentioned earlier, and a bourdon pressure gage were mounted on this aluminum tube.

D. COOLING SECTION

1. Coolant Sump

A 0.15 m³, rectangular sump for the water-ethylene glycol mixture was made of 13 mm Plexiglas sheet. The sides were glue jointed using a methylene chloride solution with additional support provided by small screws. The tank was placed on a wooden

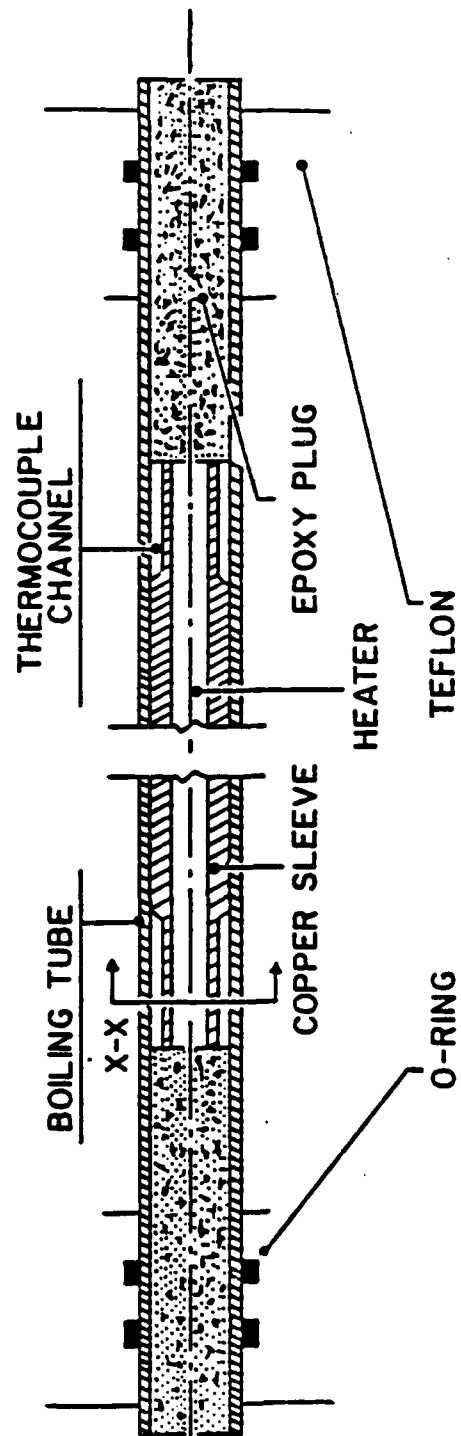
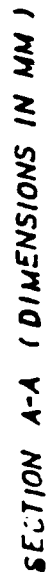


Figure 5. Schematic of the Test Tube



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platform to separate it from the concrete floor and all sides were insulated with 22 mm sheet insulation. The coolant was a 52% mixture of ethylene glycol/distilled water producing a solution freezing point of approximately -25 °C.

2. Refrigeration Plants

A 1/2 ton R-502 and a 1/4 ton R-12 refrigeration plant were used to chill the ethylene glycol/water mixture. Each consisted of a hermetically sealed compressor assembly, an air cooled condenser, a receiver, a filter-dryer, a pressure regulator, a temperature control switch and a thermostatic expansion valve. A counter current heat exchanger was used as the evaporator for the R-502 plant. An evaporator for the R-12 plant was constructed of 9.5 mm copper tubing which was coiled and placed directly in the coolant sump. Both plants were controlled by a temperature control switch with each plant having its own thermostatic expansion valve. The plants were adjusted to maintain coolant temperatures at about -17 °C. Figure 7 shows a schematic of the R-502 refrigeration plant. Figure 1 shows placement of the R-12 refrigeration plant evaporator.

3. Pump and Control Valve

The two 8 gpm, 115 V Burks turbine type, positive-displacement pumps were floor mounted next to the coolant sump. One pumped the ethylene glycol/water coolant mixture through the R-502 counter-current heat exchanger. The other pumped the coolant mixture to the condensing coil via control valve VC (see Figure 1). Valve VC was the operators primary control device to maintain saturation pressure at a desired value by varying the coolant flow rate (and hence the condensation rate) in the condenser. A bypass line was also installed on the discharge line from the pump. Discharge bypass was controlled by valve V9. The bypass line served to avoid overloading the positive displacement pump when small heat loads were placed on the condenser (low coolant flow rates). The bypass return line returned to the sump via a penetration in the top of the tank, where the coolant return stream from the condenser returned as well.

E. R-114 RESERVOIR

The R-114 reservoir was an aluminum cylindrical vessel, 230 mm in diameter and 254 mm in height. The reservoir was equipped with a transparent plastic tubular sight glass to monitor liquid level. The reservoir was located within the apparatus enclosure at a vertical location above that of the evaporator and below that of the condenser to facilitate both gravity flow from the condenser to the reservoir and from the reservoir

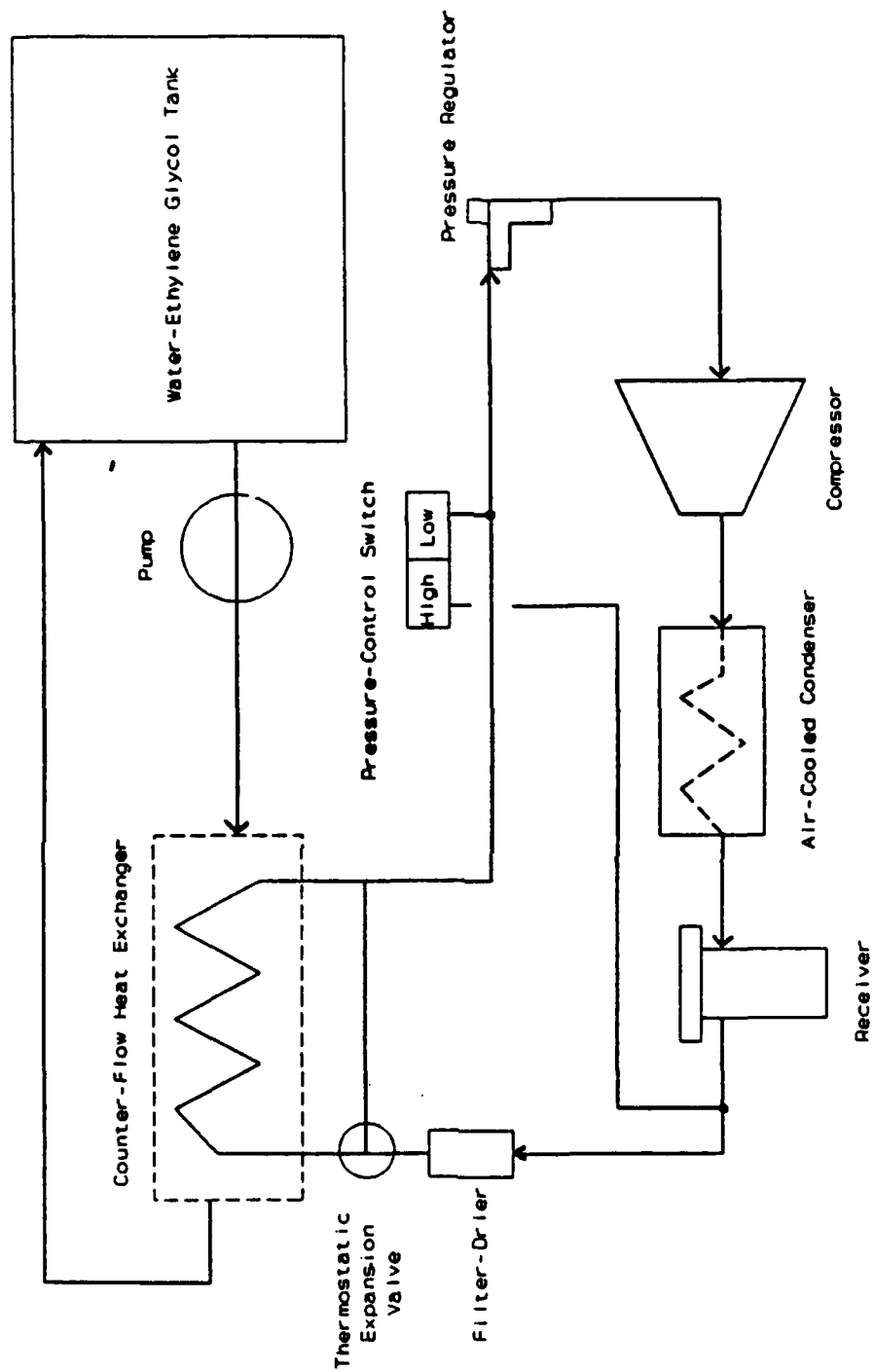


Figure 7. Schematic of R-502 Refrigeration System

to the evaporator. The reservoir could be replenished from an outside source (storage cylinder) via a connection on the vacuum line from the condenser. Vapor from the storage cylinder was condensed in the condenser and drained into the reservoir. The arrangement of the reservoir is shown in Figure 1.

F. APPARATUS ENCLOSURE

The apparatus (apart from the cooling subsystem) was contained in an aluminum framed, plexiglas enclosure. The enclosure consisted of a rectangular welded frame approximately 1 m x 0.5 m x 0.6 m. The frame was divided into upper and lower halves with the lower half of the frame straddling and enclosing the coolant sump. The upper half of the frame was enclosed at the top and bottom with aluminum sheet. The four remaining sides were enclosed with 13 mm Plexiglas. The opposing 0.5 m x 0.6 m plexiglas sides were equipped with hinges to allow access to the interior. The refrigeration plants, pumps, and heat exchanger were located on the laboratory floor adjacent to the enclosure. Data acquisition equipment was located in a separate cabinet also adjacent to the enclosure. The enclosure provided some insulation from ambient conditions and provided a safety barrier between personnel and the apparatus should one of the glass vessels fail.

G. INSTRUMENTATION

1. Power Measurement

A 240 volt AC supply was used as the power source for the apparatus and was controlled via a variac. Output from the variac ranged from 0-220 V, 0-5 A, adjustable by the operator, to obtain a desired heat flux at the tube surface. Power input to the tube heater was measured with an AC current sensor and a voltage sensor (both sensors output in volts). The voltage sensor output was also processed through an AC-DC true R.M.S. converter which provided a proportional output signal (also in volts). The current and R.M.S. voltage output were input to the data acquisition system. Calibration of power measurement was checked by comparing voltage and amperage measurements against a digital voltmeter and ammeter. The power measurement system is shown schematically in Figure 8.

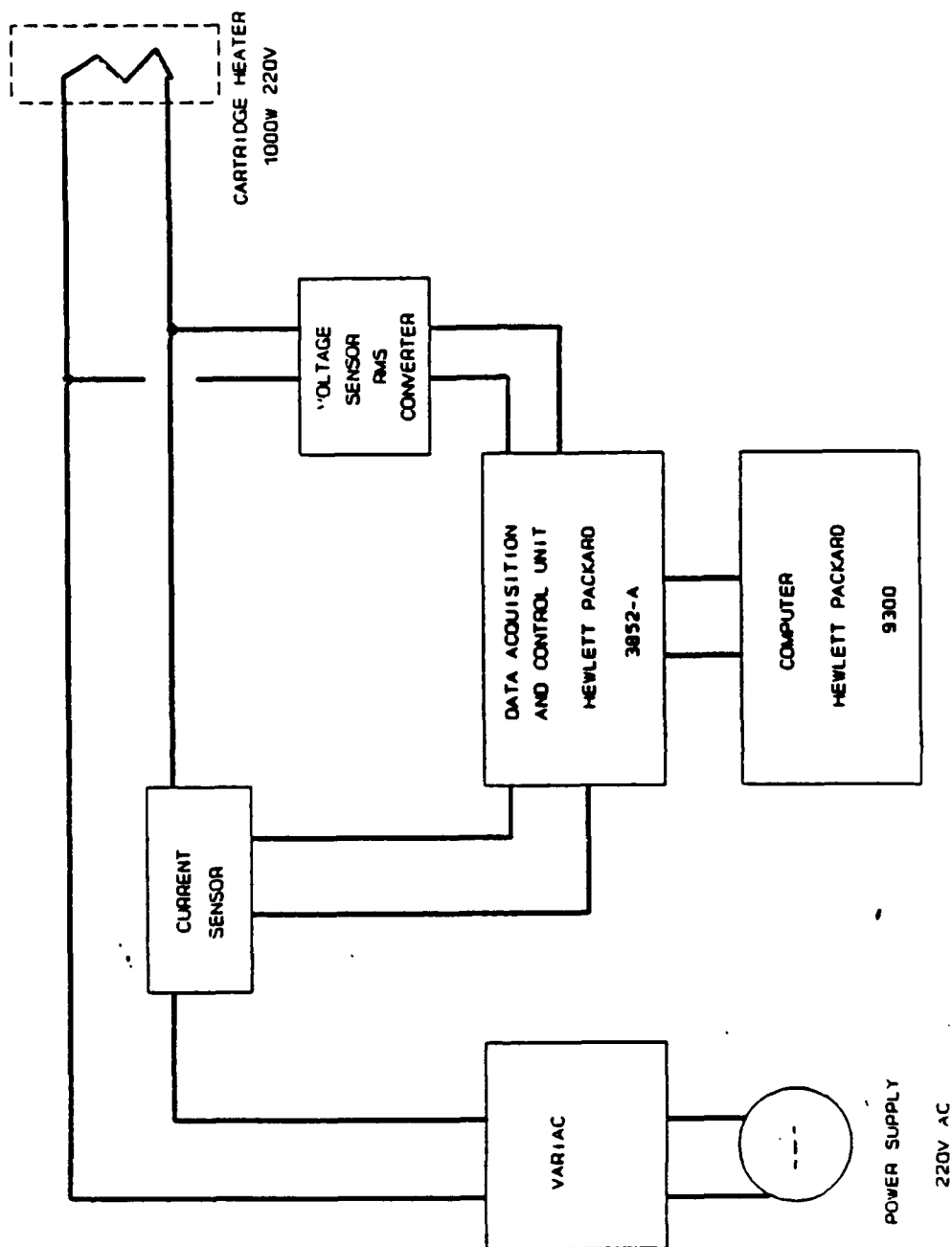


Figure 8. Schematic of the Power Measurement

2. Temperature Measurement

Several temperatures were monitored throughout the apparatus. These were

- Average test tube wall temperature (using the 8 thermocouples positioned as mentioned above).
- Pool temperature (three thermocouples located at three different positions longitudinally within the pool but at approximately the same height)
- Coolant sump temperature (one thermocouple)

The pool thermocouples were inserted into special housings that penetrated the evaporator endplates (Figure 9). The main body of the housing was manufactured from stainless steel (low thermal conductivity) to minimize errors in pool temperature measurement due to conduction from the surroundings through the housing. The tip of the housing was manufactured from copper to take advantage of copper's high thermal conductivity and to minimize the temperature difference between the pool and the thermocouple.

Copper-constantan thermocouples were used for all measurements. Thermocouples were read directly by a Hewlett-Packard 3497A data acquisition system controlled by a Hewlett-Packard 9826 computer. The average temperature for each thermocouple was obtained by scanning its output 20 times over 5 seconds and taking an average.

H. DATA ACQUISITION AND REDUCTION

All sensor outputs (thermocouples, current sensor and R.M.S. voltage) were analyzed by a Hewlett-Packard 9826 computer and the data stored using the iterative data collection/reduction program DRP72 (Sugiyama's single tube program DRP71 [Ref. 1] was used during initially repeatability experiments). The program was controlled (by the operator) by keyboard interaction to prompt the system to take desired steps. Raw data was stored on the computer hard drive while a printout of reduced data was provided on a Hewlett-Packard Inkjet printer. Channel assignments for the various sensor inputs to the data acquisition system are shown in Table 2.

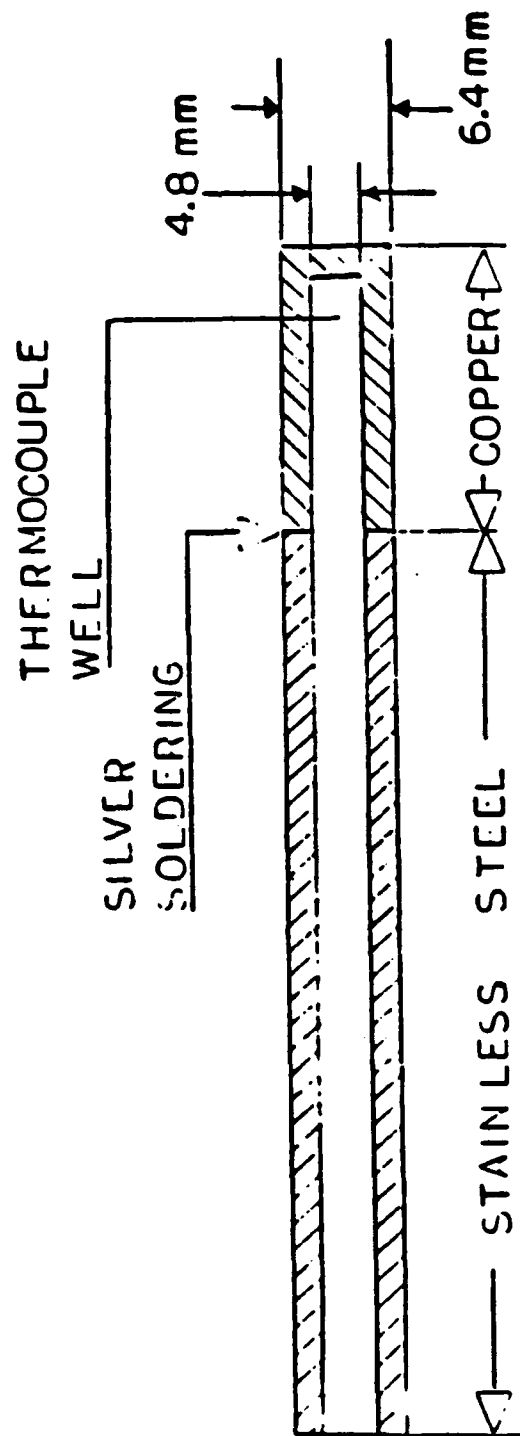


Figure 9. Sketch of Thermocouple Housing

Table 2. HP 3497A CHANNEL ASSIGNMENTS

Channel	Assignment
00-07	Upper test tube wall temperatures
08-15	Lower test tube wall temperatures
16-18	Pool liquid temperatures
19	Coolant sump temperature
20	RMS voltage tube heaters
21	Upper tube current sensor
22	Lower tube current sensor

Following data acquisition, the data were reduced utilizing the following procedure¹:

1. Input the name of the user-specified file to be stored on hard drive.
2. Select number of tubes to be powered and from which tube data is to be collected (upper or lower).
3. Select tube type (all dimensions of the boiling test tubes are then automatically selected).
4. Set desired saturation temperature ($^{\circ}\text{C}$) of the pool (for these tests, 2.2°C was used, corresponding to approximately 1 atmosphere).
5. Input desired heat flux setting.
6. Set desired heat fluxes by adjusting appropriate variac.
7. Set desired saturation temperature by adjusting flow of coolant through condenser coils with control valve VC.
8. Once saturation temperature is achieved, wait for steady state conditions (minimum of 5 minutes) prior to taking data.
9. Prompt data acquisition unit to scan all channels listed in Table 2. All channel readings are made in volts and stored in user specified fields.
10. Compute parameters from these voltages (i.e. temperature and power).
11. Compute the heat transfer rate from the cartridge heater.
12. Compute the average wall temperature of the test tubes and calculate the wall superheat ($T_{\text{wall}} - T_{\text{sat}}$).
13. Compute the physical properties of R-114 using the property correlations (see Sugiyama[Ref. 1]) at film temperature $((T_{\text{wall}} - T_{\text{sat}})/2)$.
14. Compute the natural convection heat-transfer coefficient of R-114 from the unheated ends of the test tubes.
15. Compute heat losses from the unheated ends of each tube.
16. Calculate heat flux from the heated length of each tube.
17. Calculate the heat-transfer coefficient of the R-114 from the heated length of each tube.
18. Store heat flux and wall superheat for each data set in user specified field.
19. Plot the data using available software. For this study, plots were produced on the NPS mainframe computer.

Sample calculations of the above procedure are given in Appendix A.

¹ This procedure was essentially identical to that followed by Sugiyama [Ref. 1] and therefore his procedure is largely reproduced.

IV. EXPERIMENTAL PROCEDURE

A. ASSEMBLY

The mechanical assembly of the tubes within the evaporator was very straight forward and will not be discussed in great detail. However the preparatory steps following assembly are important from the point of view of ensuring a leaktight apparatus to prevent loss of R-114 from the system and the intrusion of noncondensable gases into the system. Additionally it should be noted that vertical alignment of tubes was ensured by using an air bubble level.

1. Pressure Test of the Apparatus

Following reassembly of the evaporator, a pressure test was conducted on the apparatus by pressurizing the system (with air) up to 10 psig. A soap-water mixture then was sprayed on all joints and leaks were detected by bubble formation from the soap-water mixture. Any leaks were then repaired. The apparatus was repeatedly pressure tested until there were no "visible" leaks detected.

2. Vacuum Test

Following a successful pressure test, the apparatus was evacuated (using the vacuum pump) to approximately 27 inHg. The apparatus was then allowed to stand overnight. If an appreciable vacuum loss was observed (i.e. a drop of more than 1 inHg. in a 24 hour period), the whole process was repeated, beginning with a pressure test, until all leaks were corrected.

3. Filling the Evaporator

After the apparatus was successfully vacuum tested, the evaporator was filled from the R-114 reservoir. The pressures were first equalized between the evaporator and the reservoir by cracking open valve V7. R-114 liquid was then drained by gravity into the evaporator through valve V6 until the liquid reached the desired evaporator level, approximately 10 mm above the top of the upper tube. Once the evaporator was filled, the reservoir was isolated from the rest of the apparatus by closing all connecting valves.

4. Sensor Connections

Thermocouple leads and any other sensor connections were not reconnected until the evaporator was successfully filled without leaks. This prevented unnecessary wear and tear on the heater leads and thermocouple wire due to the large number of tube changes required.

5. Degassing and Acquisition Channel Check

Once all connections were made, program SETUP72 checked the output on all channels. Any erroneous output was promptly investigated and the necessary corrections made. Before any heat was applied to either test tube, the system pressure was reduced to the desired saturation pressure by opening flow of the coolant mixture to the condenser. Each tube in turn was boiled vigorously at the highest heat flux setting (approximately 80 kW/m^2) for about 10 minutes in order to degas the refrigerant and to remove excess air from the tube surface cavities. Noncondensable gases then collected at the top of the condenser and were removed by the vacuum pump. During the degassing procedure, program SETUP72 was again used to observe thermocouple readings and power sensors to ensure proper operation. Any faulty thermocouples were marked to ensure they were excluded during data runs. Following degassing, the apparatus was secured and the tubes allowed to soak overnight in the R-114 pool to provide good surface wetting.

B. NORMAL PROCEDURE

The following procedure was used to obtain heat transfer data²:

1. Prior to system startup, the refrigeration plants were operated for approximately 1 hour to reduce the coolant sump temperature to about -15°C .
2. The data acquisition/control unit, computer and variac panel were switched on.
3. The computer program SETUP72 was loaded and run: 1) All data acquisition channels were then rechecked. 2) A power output of approximately 2.5 Watts was input into each tube to check operation of the heater and power sensors. 3) The average temperature of the refrigerant was slowly reduced to 2.2°C by circulating a small amount of coolant through the condenser.
4. The data acquisition program DRP72 was loaded and run.
5. The desired heat flux setting for the lower tube was input to the program and the lower tube variac adjusted to give the desired heat flux (within $\pm 500 \text{ W/m}^2$).
6. The control valve VC was adjusted to regulate the flow of cooling liquid through the condenser to maintain a constant saturation temperature at a given heat flux. Desired versus actual saturation temperatures were monitored continuously by the program until they agreed to within $\pm 0.1^\circ\text{C}$.
7. For each data point, conditions in the evaporator were allowed to stabilize for at least five minutes prior to taking data. The following raw data were measured and stored in a user specified field: local test tube wall temperatures, pool liquid temperatures, sump temperature, current sensor readings and voltage sensor readings.

² Ibid

8. Two data points were taken at each desired heat flux and saturation temperature. The following processed data were recorded as a printout: wall temperatures of the test tubes, liquid pool temperatures, vapor temperature, sump temperature, wall superheat, heat-transfer coefficient and the heat flux.
9. For each data set, the above procedure was repeated from step 5. Various heat flux steps were used to obtain uniform steps on a log-log scale. For increasing flux, smaller steps were used up until the incipience of boiling in order to accurately determine the point of incipience.

C. DATA LISTING

Data were filed using the following file name system:

- Files were given 10 character names (ex. DAT0531I52).
- The first three characters DAT simply refer to data.
- The next four characters date the file (0531 = 31 May).
- The eighth character indicated an increasing or decreasing run (I = increasing, D = decreasing).
- The ninth character indicated tube type as listed in program DRP72 (4 = smooth tube, 5 = High Flux tube).
- The tenth character indicated which program was used DRP71 or DRP72 (1 = DRP71, 2 = DRP72).
- The 11th character when present indicated successive runs for the indicated tube and indicated program for that day.

Table 3 is a listing of data runs.

Table 3. LISTING OF DATA RUNS

Data File	Tube Type	Purpose
DAT0122I51	High Flux	Cal; repeatability; single tube
DAT0123I52	High Flux	Cal; repeatability; single tube
DAT0125I52	High Flux	Repeatability; $p/d = 2$
DAT0127I2	High Flux	Repeatability; $p/d = 2$
DAT0130I52	High Flux	Repeatability; $p/d = 2$
DAT0130D52	High Flux	Repeatability; $p/d = 2$
DAT0312I42	Smooth	Data; repeatability; $p/d = 2$
DAT0312D41	Smooth	Data; repeatability; $p/d = 2$
DAT0313I41	Smooth	Repeatability; $p/d = 2$
DAT0313D41	Smooth	Repeatability; $p/d = 2$
DAT0317I42	Smooth	Repeatability; $p/d = 2$
DAT0317D42	Smooth	Repeatability; $p/d = 2$
DAT0320I41	Smooth	Repeatability; $p/d = 2$
DAT0320D41	Smooth	Repeatability; $p/d = 2$
DAT0330I42	Smooth	Repeatability; $p/d = 2$
DAT0330D42	Smooth	Repeatability; $p/d = 2$
DAT0331I42	Smooth	Data; $p/d = 2$; 500 W/m^2 on lower tube
DAT0331D42	Smooth	Data; $p/d = 2$; 500 W/m^2 on lower tube
DAT0401I42	Smooth	Data; $p/d = 2$; 1 kW/m^2 on lower tube
DAT0401D42	Smooth	Data; $p/d = 2$; 1 kW/m^2 on lower tube
DAT0404I42	Smooth	Data; $p/d = 2$; 1 kW/m^2 on lower tube
DAT0404I421	Smooth	Data; $p/d = 2$; 1 kW/m^2 on lower tube
DAT0404D421	Smooth	Data; $p/d = 2$; 1 kW/m^2 on lower tube
DAT0406I42	Smooth	Data; $p/d = 2$; 10 kW/m^2 on lower tube

Continuation of Table 3.

Data File	Tube Type	Purpose
DAT0406D42	Smooth	Data; $p/d = 2$; 10 kW/m^2 on lower tube
DAT0407I42	Smooth	Data; $p/d = 2$; 25 kW/m^2 on lower tube
DAT0407D42	Smooth	Data; $p/d = 2$; 25 kW/m^2 on lower tube
DAT0408I42	Smooth	Data; $p/d = 2$; 3 kW/m^2 on lower tube
DAT0408D42	Smooth	Data; $p/d = 2$; 3 kW/m^2 on lower tube
DAT0410I42	Smooth	Data; $p/d = 2$; Tubes run up together
DAT0410D42	Smooth	Data; $p/d = 2$; Tubes run down together
DAT0415I42	Smooth	Data; $p/d = 1.8$; 10 kW/m^2 on lower tube
DAT0415D42	Smooth	Data; $p/d = 1.8$; 10 kW/m^2 on lower tube
DAT0415I421	Smooth	Data; $p/d = 1.8$; 25 kW/m^2 on lower tube
DAT0415D421	Smooth	Data; $p/d = 1.8$; 25 kW/m^2 on lower tube
DAT0417I42	Smooth	Data; $p/d = 1.8$; no power on lower tube
DAT0417D42	Smooth	Data; $p/d = 1.8$; no power on lower tube
DAT0418I42	Smooth	Data; $p/d = 1.8$; 1 kW/m^2 on lower tube
DAT0418D42	Smooth	Data; $p/d = 1.8$; 1 kW/m^2 on lower tube
DAT0419I42	Smooth	Data; $p/d = 1.8$; 3 kW/m^2 on lower tube
DAT0419D42	Smooth	Data; $p/d = 1.8$; 3 kW/m^2 on lower tube
DAT0423I42	Smooth	Data; $p/d = 1.5$; no power on lower tube

Continuation of Table 3

Data File	Tube Type	Purpose
DAT0423D42	Smooth	Data; p/d = 1.5; no power on lower tube
DAT0424I42	Smooth	Data; p/d = 1.5; 3 kW/m ² on lower tube
DAT0424D42	Smooth	Data; p/d = 1.5; 3 kW/m ² on lower tube
DAT0425I42	Smooth	Data; p/d = 1.5; 1 kW/m ² on lower tube
DAT0425D42	Smooth	Data; p/d = 1.5; 1 kW/m ² on lower tube
DAT0426I42	Smooth	Data; p/d = 1.5; 10 kW/m ² on lower tube
DAT0426D42	Smooth	Data; p/d = 1.5; 10 kW/m ² on lower tube
DAT0427I42	Smooth	Data; p/d = 1.5; 25 kW/m ² on lower tube
DAT0427D42	Smooth	Data; p/d = 1.5; 25 kW/m ² on lower tube
DAT0430I52	High Flux	Data; p/d = 1.5; 1 kW/m ² on lower tube
DAT0430D52	High Flux	Data; p/d = 1.5; 1 kW/m ² on lower tube
DAT0501I52	High Flux	Data; p/d = 1.5; 10 kW/m ² on lower tube
DAT0501D52	High Flux	Data; p/d = 1.5; 10 kW/m ² on lower tube
DAT0501I522	High Flux	Data; p/d = 1.5; 25 kW/m ² on lower tube
DAT0501D522	High Flux	Data; p/d = 1.5; 25 kW/m ² on lower tube
DAT0502I52	High Flux	Data; p/d = 1.5; 3 kW/m ² on lower tube
DAT0502D52	High Flux	Data; p/d = 1.5; 3 kW/m ² on lower tube
DAT0503I52	High Flux	Data; p/d = 1.5; no power on lower tube

Continuation of Table 3.

Data File	Tube Type	Purpose
DAT0503D52	High Flux	Data; p/d = 1.5; no power on lower tube
DAT0506I52	High Flux	Data; p/d = 1.8; no power on lower tube
DAT0506D52	High Flux	Data; p/d = 1.8; no power on lower tube
DAT0507I52	High Flux	Data; p/d = 1.8; 1 kW/m ² on lower tube
DAT0507D52	High Flux	Data; p/d = 1.8; 1 kW/m ² on lower tube
DAT0508I52	High Flux	Data; p/d = 1.8; 3 kW/m ² on lower tube
DAT0508D52	High Flux	Data; p/d = 1.8; 3 kW/m ² on lower tube
DAT0508I521	High Flux	Data; p/d = 1.8; 10 kW/m ² on lower tube
DAT0508D521	High Flux	Data; p/d = 1.8; 10 kW/m ² on lower tube
DAT0509I52	High Flux	Data; p/d = 1.8; 25 kW/m ² on lower tube
DAT0509D52	High Flux	Data; p/d = 1.8; 25 kW/m ² on lower tube
DAT0509D52	High Flux	Data; p/d = 1.8; 25 kW/m ² on lower tube
DAT0515I52	High Flux	Data; p/d = 2; 25 kW/m ² on lower tube
DAT0515D52	High Flux	Data; p/d = 2; 25 kW/m ² on lower tube
DAT0516I52	High Flux	Data; p/d = 2; 10 kW/m ² on lower tube
DAT0516D52	High Flux	Data; p/d = 2; 10 kW/m ² on lower tube
DAT0517I52	High Flux	Data; p/d = 2; 1 kW/m ² on lower tube
DAT0519I52	High Flux	Data; p/d = 2; 3 kW/m ² on lower tube

Continuation of Table 3

Data File	Tube Type	Purpose
DAT0520I52	High Flux	Data; $p/d = 2$; no power on lower tube
DAT0529I52	High Flux	Data; $p/d = 2$; tubes run up/down together
DAT0530I52	High Flux	Data; $p/d = 2$; lower tube position plugged

V. RESULTS AND DISCUSSION

It should be noted and it is stressed that results are expressed in terms of enhancement of the upper tube over a single tube and that the results are applicable to this apparatus. These results may not be reproducible outside of this apparatus.

A. REPRODUCIBILITY

To investigate repeatability, tests were conducted with both a 'single' High Flux and smooth tube (with only the upper tube operating). Runs were conducted using both program DRP71 (from Sugiyama's single tube work [Ref. 1]) and DRP72 with no heat flux applied to the bottom tube. This ensured that the new program DRP72 performed correctly. An additional set of runs were made using the pair of smooth tubes with a heat flux of 1 kW/m^2 applied to the lower tube using program DRP72. The runs for all these comparisons are listed in Table 4. A pitch-to-diameter ratio of 2 was used for the runs listed in Table 4. A plot of heat flux vs. wall superheat (Thetab) for these runs is shown in Figure 10 through Figure 12. Figure 10 shows the 'single' smooth tube data together with the single smooth tube data of Sugiyama [Ref. 1]. The three runs agree very well and are within 10% of Sugiyama's data; any discrepancy is attributed to the presence of the unheated lower tube modifying the flow over the upper tube. Clear evidence of hysteresis is seen as with Sugiyama's work; as the heat flux is decreased, a closed loop is formed indicating that as the nucleation sites die out, the transfer mechanism returns to one of natural convection. Figure 11 shows the 'single' High Flux tube data together with the single tube High Flux data of Sugiyama [Ref. 1]. Again good agreement is obtained except at the lowest heat fluxes and lowest ΔT 's where discrepancies of up to 50% are noted. However, due to the very high uncertainty in this region (marked on Figure 11), primarily due to uncertainty in the wall temperature measurement due to the fabrication procedures, the agreement is still considered reasonable. It should also be noted that run DAT0530 was conducted with plugs in place of the bottom tube (as opposed to the bottom tube having zero applied heat flux) and also shows excellent agreement. This indicates quite clearly that with the lower tube off, the upper tube behaves almost exactly like a single tube. Note also that the hysteresis 'loop' is open (again similar to the work of Sugiyama) indicative of the fact that there are still a significant number of active nucleation sites operating with the High Flux tube even at heat fluxes as low as 1000 W/m^2 . Figure 12 shows the three smooth tube runs con-

ducted with a 1 kW/m^2 heat flux applied to the bottom tube. Without discussing the significance of the results here (see section B.), it can be seen that repeatability is good and within 5% for all three data sets. Based on Figure 10 through Figure 12, data repeatability and agreement with past single tube work carried out on the same apparatus is considered good.

Table 4. DATA RUNS USED FOR REPEATABILITY

Data Set	Tube Type	Lower Tube Setting
DAT0313I41	smooth	no power on lower tube
DAT0313D41	smooth	no power on lower tube
DAT0320I41	smooth	no power on lower tube
DAT0320D41	smooth	no power on lower tube
DAT0330I42	smooth	no power on lower tube
DAT0330D42	smooth	no power on lower tube
DAT0401I42	smooth	1 kW/m^2
DAT0401D42	smooth	1 kW/m^2
DAT0404I42	smooth	1 kW/m^2
DAT0404D42	smooth	1 kW/m^2
DAT0407I42	smooth	1 kW/m^2
DAT0407D42	smooth	1 kW/m^2
DAT0123I52	High Flux	no power on lower tube, increasing run only
DAT0130I52	High Flux	no power on lower tube
DAT0130D52	High Flux	no power on lower tube
DAT0530I52	High Flux	lower tube removed and position plugged, increasing and decreasing run recorded in this file

B. INFLUENCE OF THE LOWER TUBE

To investigate the influence of a lower upon an upper tube, each upper tube (for both types of tube surface) was run up and down (starting in the convection region) through various heat flux settings for three different pitch-to-diameter (p/d) ratios and five different fixed heat flux settings on the lower tube. Note that in each test, the same tube surface was used for the upper tube and the lower tube (i.e. the surfaces were never mixed). The p/d ratios used were 1.5, 1.8 and 2. A p/d ratio of 2 was selected to match

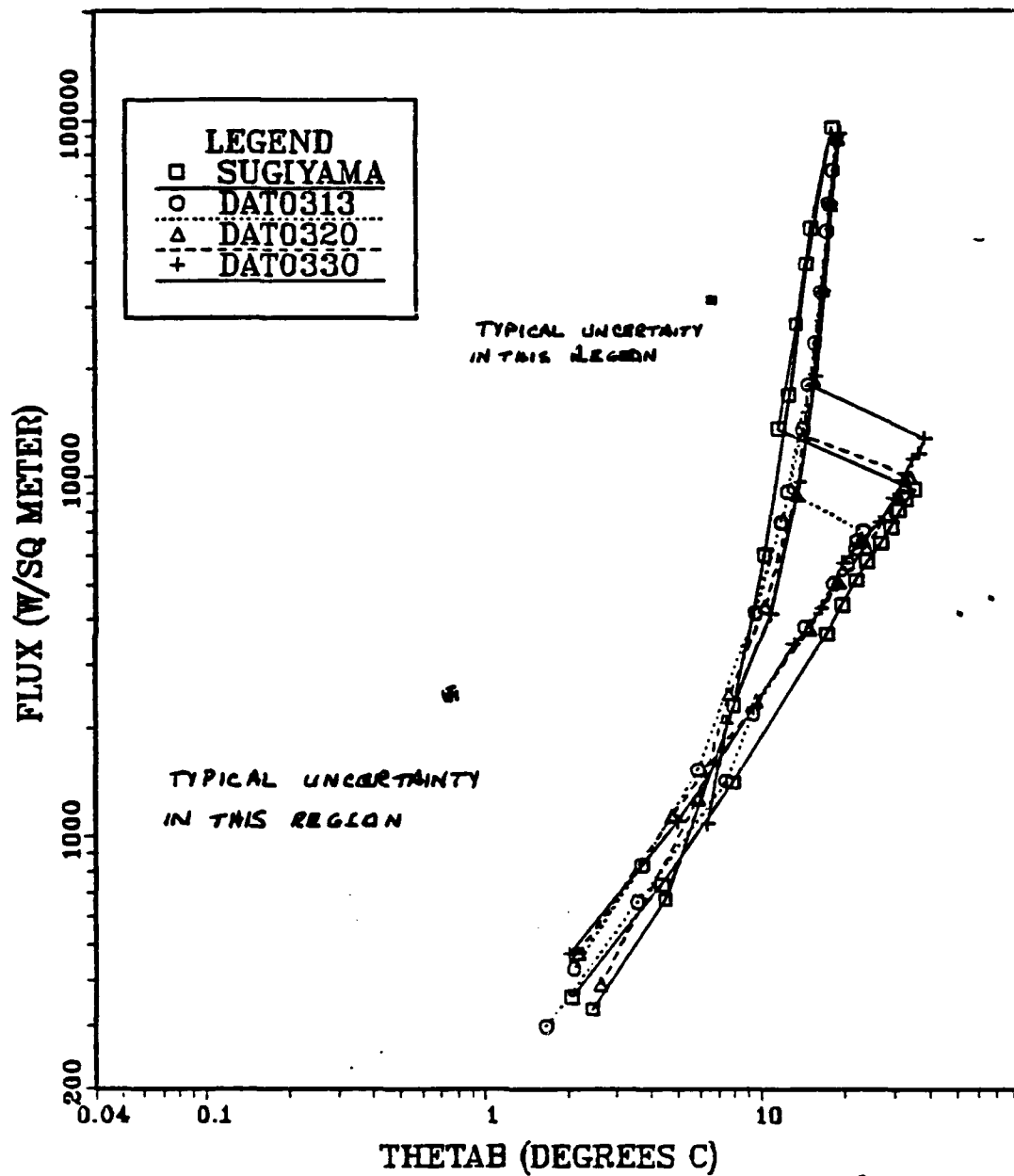


Figure 10. Repeatability Comparison for Smooth Tube, No Heat Flux on Lower Tube

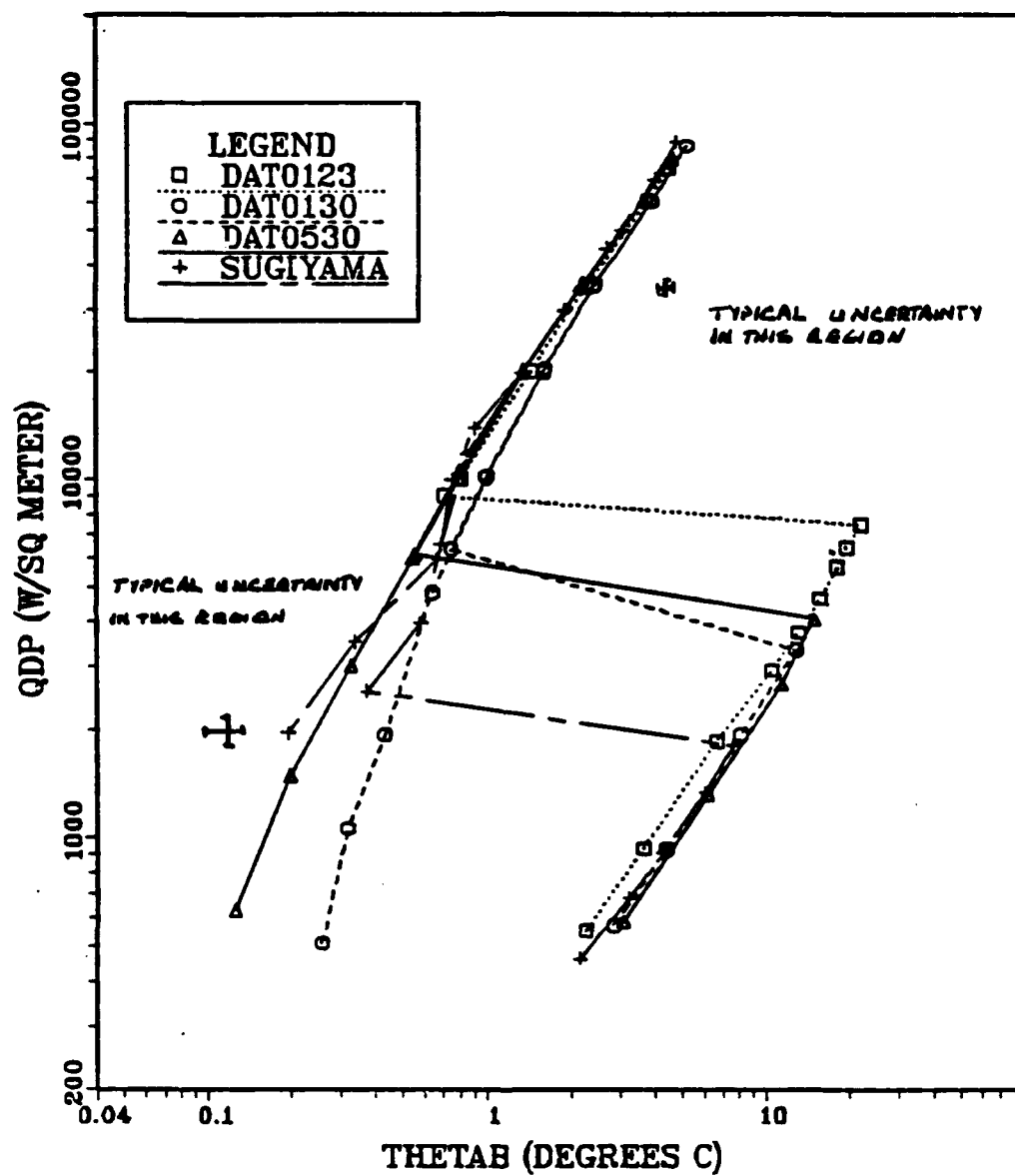


Figure 11. Repeatability Comparison for Hi Flux Tube, No Heat Flux on Lower Tube

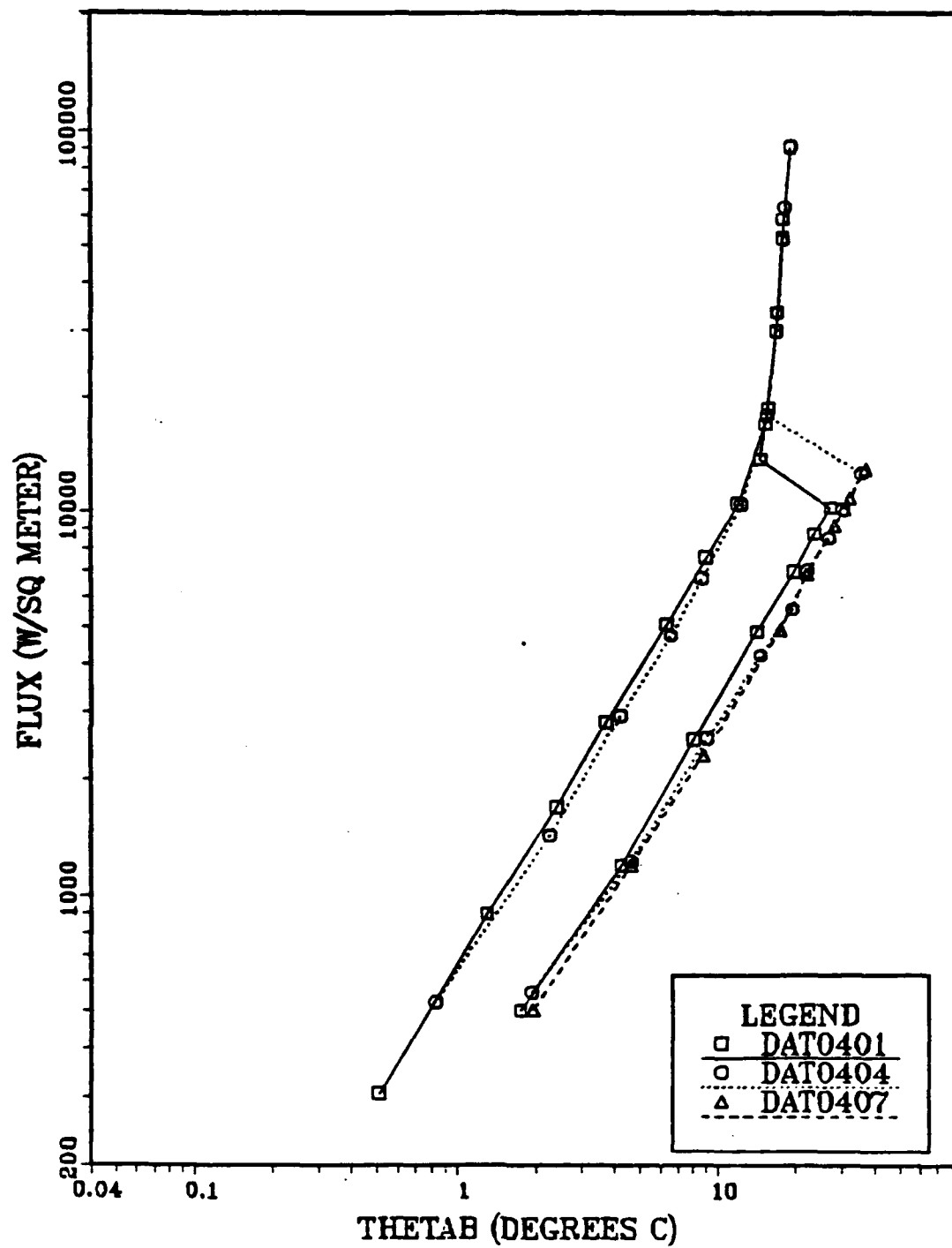


Figure 12. Repeatability Comparison for Smooth Tube, Heat Flux of 1 kW/m^2 on Lower Tube

the vertical pitch, not only in Naval centrifugal flooded evaporators, but also in the bundle apparatus in the Heat Transfer Laboratory. The fixed lower tube heat flux settings (LTHFS) used were 0, 1, 3, 10 and 25 kW/m^2 (there was one test conducted with a lower tube heat flux setting of 500 W/m^2). To evaluate the influence of the lower tube, the data has been presented in two ways: the first by common p/d ratio and the second by common LTHFS. In every case, plots of heat flux vs ΔT are shown.

1. The Effect of Heating the Lower Tube

a. Smooth Tube p/d Ratio of 2

Figure 13 shows data taken for a p/d ratio of 2 for the six LTHFS labeled in the legend representing kW/m^2 and CC representing the Churchill and Chu correlation [Ref. 2]. This labeling was used for all the 5 subsequent plot legends. An extra run was made at this pitch with a LTHFS of 500 W/m^2 for comparison. The natural convection regime shows very small enhancements with increasing LTHFS of up to 3 kW/m^2 . Of note is that for LTHFS of 0, 0.5, 1, and 3 kW/m^2 , the lower tube was in the convection regime at the beginning of the increasing run. For the 10 and 25 kW/m^2 case the lower tube had nucleated immediately and was nucleating for the entire run. The natural convection curves are still very close to values calculated from Churchill and Chu's correlations [Ref. 2] and relatively parallel with one another. It can be seen that for a LTHFS of 500 W/m^2 , the top tube behaves almost as if it were a single tube (i.e. agrees with a LTHFS of 0). In this case, the lower tube remained in the natural convection regime for the *entire* run and shows that if this is the case, little to no enhancement of the upper tube is obtained at any heat flux. The point of incipience is different for each LTHFS and proved to be a fairly random event for the smooth tubes, occurring around 12 kW/m^2 . In all cases except the 0 and 500 W/m^2 , the lower tube was "seeded" by bubbles from the R-114 return line (impinging upon the lower tube) when at a high flux ($> 20 kW/m^2$) on the upper tube. The lower tube then continued to nucleate after being 'seeded' throughout the remainder of the run. The LTHFS of 0, 0.5, 1 and 3 kW/m^2 showed enhancement upon nucleation, jumping to a common nucleate boiling curve. This entire run showed a very definite hysteresis effect and was very similar to Sugiyama's [Ref. 1] single tube data. Following nucleation, the four lower LTHFS followed an identical nucleate boiling curve for the remainder of the increasing run. On the decreasing run, the two lowest LTHFS showed a gradual return to the convection curve indicating a gradual deactivation of nucleation sites as heat flux was reduced on the upper tube. This coincided with no nucleation on the lower tube and also agreed well with Sugiyama's [Ref. 1] single tube results. The remaining LTHFS departed from this

curve (on the decreasing run) and showed significant enhancements (almost an order of magnitude over a single tube at the lowest heat fluxes). The enhancement increased with increasing the LTHFS until at LTHFS above 10 kW/m^2 , additional enhancement was minimal. The curves followed by LTHFS greater than 1 kW/m^2 during the decreasing run were also parallel to the increasing run natural convection curves. This suggests strong convection effects on the upper tube when the lower tube is nucleating and heat flux setting on the upper tube is below 10 kW/m^2 . This agrees well with the data of Fujita *et al.* [Ref. 13]. It should be noted that all LTHFS followed the same curve above an upper tube heat flux setting of approximately 20 kW/m^2 showing no effect of LTHFS at high flux settings on the upper tube. This too is in agreement with Fujita *et al.*. Of particular note is that the two highest LTHFS follow the same curve for both increasing and decreasing runs, indicating complete elimination of hysteresis prominent in single tube data. The above discussion indicates a significant effect of the lower tube upon the upper tube when the lower tube is nucleating. There are almost negligible enhancements when both tubes are in the convection regime.

b. Smooth Tube p/d Ratio of 1.8.

The smooth tube runs with a p/d ratio of 1.8, shown in Figure 14, show very similar results to that for a p/d of 2. As before for LTHFS of 0, 1 and 3 kW/m^2 , both tubes begin in the convection regime for the increasing run: again no significant enhancement is seen in this region, although these curves are in better agreement with Churchill and Chu [Ref. 2]. For a given LTHFS, onset of nucleate pool boiling (ONB) occurs at different heat fluxes than in Figure 13, demonstrating the random nature of this phenomena. A common nucleate boiling curve is followed by all LTHFS runs above an upper tube heat flux setting of about 20 kW/m^2 . Hysteresis effects are similar for low LTHFS as are the elimination of hysteresis for the two highest LTHFS. The lower tube was seeded by bubbles from the R-114 return line at high upper tube heat flux for all LTHFS (except 0). When compared with Figure 13, the same enhancement factors are seen at all but the highest heat fluxes, where the 1.8 p/d shows a slight enhancement over the 2 p/d . This will be shown more clearly on a later graph.

c. Smooth Tube p/d of 1.5

The same trends and enhancements seen in the previous two p/d ratios are also seen in Figure 15. LTHFS of 0, 1 and 3 are very similar to the previous two p/d ratios with no appreciable enhancement in the convection region. The lower tube started in the convection region for LTHFS of 0, 1 and 3, and was nucleating throughout for LTHFS of 10 and 25 kW/m^2 . The lower tube nucleated via 'seeding' at high fluxes

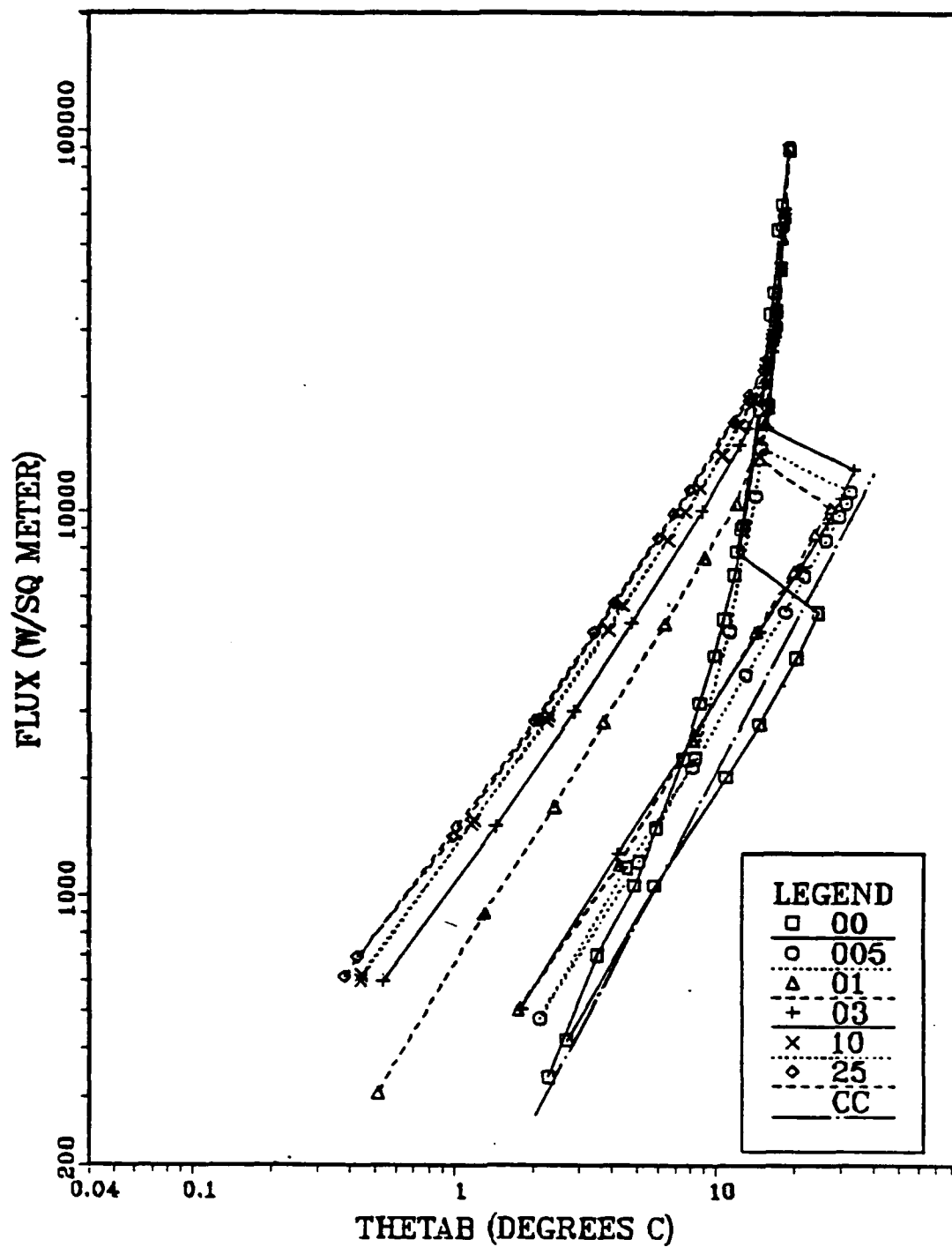


Figure 13. Comparison of Lower Tube Flux Settings for a p/d Ratio of 2 for Smooth Tube

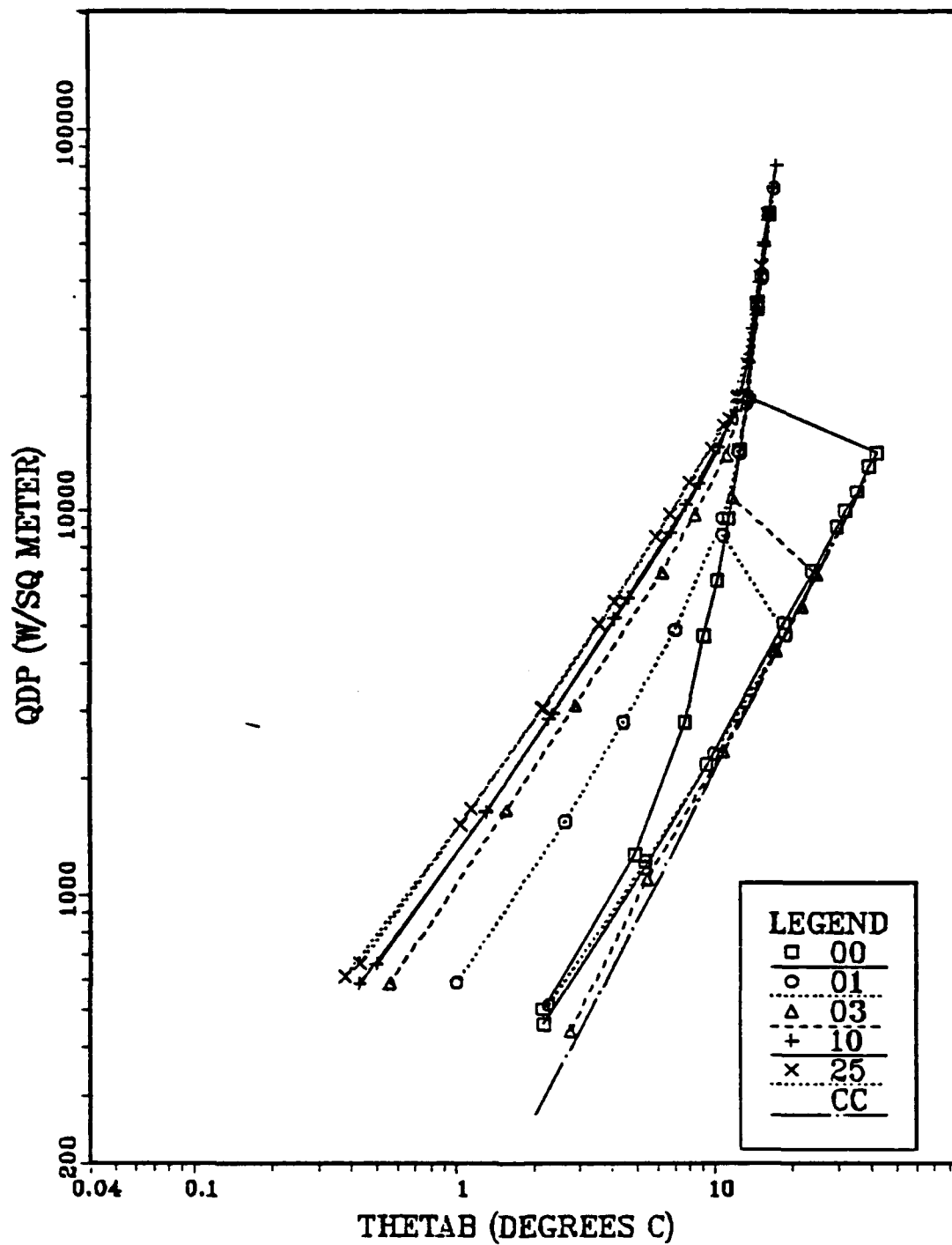


Figure 14. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.8 for Smooth Tube

on the upper tube as for the previous two p/d ratios. ONB for the upper tube continued to be a statistical phenomenon. Similar hysteresis patterns are also seen. At the highest heat flux settings, the 1.5 p/d shows a degradation compared to both the 1.8 and 2.0 p/d . This will again be shown more clearly on a later graph.

d. High Flux Tube p/d of 2

A plot of data runs made for the High Flux tube with a p/d ratio of 2 is shown in Figure 16. The convection region looks very similar to that of the smooth tubes in that they agree fairly well with Churchill and Chu [Ref. 2]. Also, there is no appreciable enhancement in the convection region for increases in LTHFS from 0 to 3 kW/m^2 . For LTHFS of 0, 1 and 3, the lower tube remained in the convection regime until nucleation of the top tube, as with the smooth tube cases. However for all the High Flux tube runs, with the exception of the 0 LTHFS, the lower tube nucleated *at the same time as* the upper tube when both tubes started in the convection regime. This appeared to be due to the explosive nature of nucleation with these enhanced surfaces which caused vapor to impinge upon the lower tube thereby causing immediate nucleation on the lower tube as well; there are probably significant shock waves set up within the pool that add to this nucleation of the lower tube as well. Once the upper tube nucleated, the three LTHFS curves jumped to a common nucleate boiling curve, and demonstrated a significant temperature overshoot, similar to that found by Sugiyama [Ref. 1] for a single High Flux Tube. These LTHFS runs followed the same nucleate boiling curve for the remainder of the increasing run and for the entire decreasing run; the form of the hysteresis loop agreed very well with Sugiyama's single tube work [Ref. 1].

The lower tube nucleated from the beginning of the increasing run for a LTHFS of 10 and 25 kW/m^2 . Unlike the smooth tubes, the hysteresis loop is not completely eliminated for these two LTHFS. These curves demonstrate that the upper tube experiences several effects during the increasing run. The segment of the curve between 500 and 1000 W/m^2 is parallel to the natural convection curves but well to the left (i.e. well enhanced), indicating strong convection effects due to the bubble plume from the lower tube sliding over the upper tube. This segment of the curve agrees very closely with that for the smooth tube in the convection region for the same pitch and the same LTHFS. This indicates that the bubbles sweeping over the upper non-nucleating High Flux tube have the same enhancement effect as on an upper non-nucleating smooth tube, i.e. it makes no difference which tube surface is used because the majority of the heat transfer is associated with the bubble plume sweeping over the upper tube from the

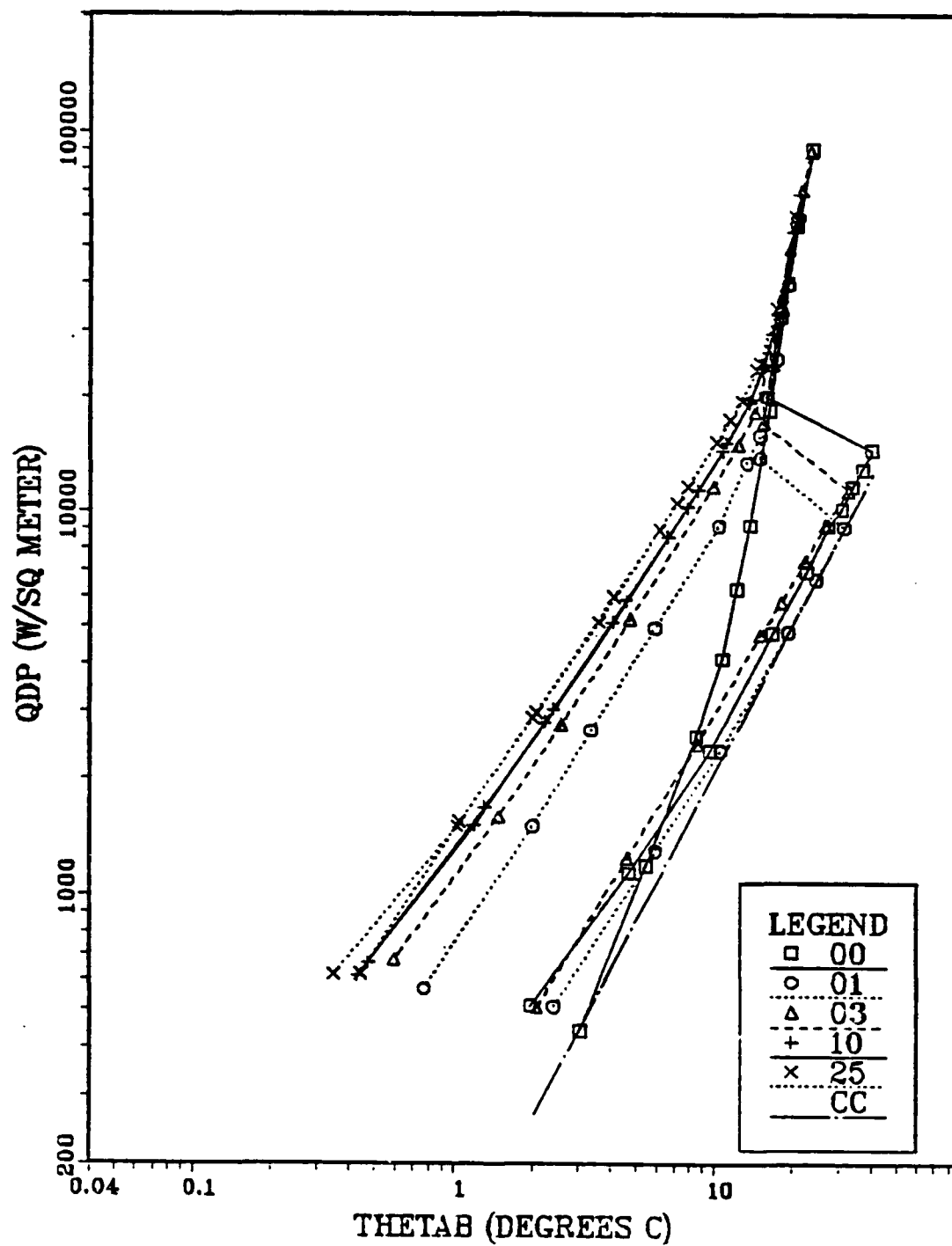


Figure 15. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.5 for Smooth Tube

nucleating tube below. This supports Cornwell's bubble sweeping hypothesis at low heat fluxes [Ref. 17]. For upper tube heat fluxes above 1000 W/m^2 , the curves for both the 10 and 25 kW/m^2 LTHFS show almost vertical slopes, indicating partial nucleation and mixed convection, eventually; at high enough heat flux as they join the same common nucleate boiling curve as before with LTHFS of 0, 1 and 3 kW/m^2 . All decreasing runs for all LTHFS followed the same curve, and agreed closely with both the 0 LTHFS and with single tube data (Sugiyama [Ref. 1]) for decreasing heat flux. There is some difference between the curves on the decreasing run at low fluxes; however these differences are within the experimental uncertainty which is largest in this region. The above suggests that there is no enhancement

of the upper tube heat transfer coefficient gained by heating the lower tube at a p/d of 2.

e. High Flux Tube p/d Ratio of 1.8

Figure 17 for a p/d of 1.8 is almost identical to that for a pitch of 2. The same effects (as discussed for Figure 16 above) apply equally to Figure 17. Convection and nucleate region curves fall on top of each other with the upper tube nucleating at almost the same heat fluxes. The first segment between 500 and 1000 W/m^2 for LTHFS of 10 and 25 kW/m^2 agrees very closely with the nucleate boiling region for the smooth tube for the same pitch. The reasons for this are also discussed above, and demonstrate the repeatability of this effect. The excellent agreement between the plots in Figure 17 and Figure 16 suggests that there is no effect of tube spacing at any heat flux. This will become clearer in later figures.

f. High Flux Tube p/d Ratio of 1.5

Figure 18 shows the plot for a pitch of 1.5 to be almost identical to the plots for pitches of 1.8 and 2. The differences in the plot are in the same areas as in the previous pitch. The upper tube nucleates at different fluxes than in the previous two pitches, again demonstrating the somewhat random nature of ONB. In all other respects the plot is identical to the previous two, further reinforcing that there is nothing to be gained from an upper enhanced tube by the presence of a nucleating lower enhanced tube except if the upper tube is in the natural convection region.

2. The Effect of Tube Spacing

a. Lower Tube Unheated

To show the effect of tube spacing, plots have been made for all three pitch-to-diameter ratios at each LTHFS used. For the base of an unheated lower tube, the data are shown in Figure 19 for both the smooth and High Flux tubes for all three

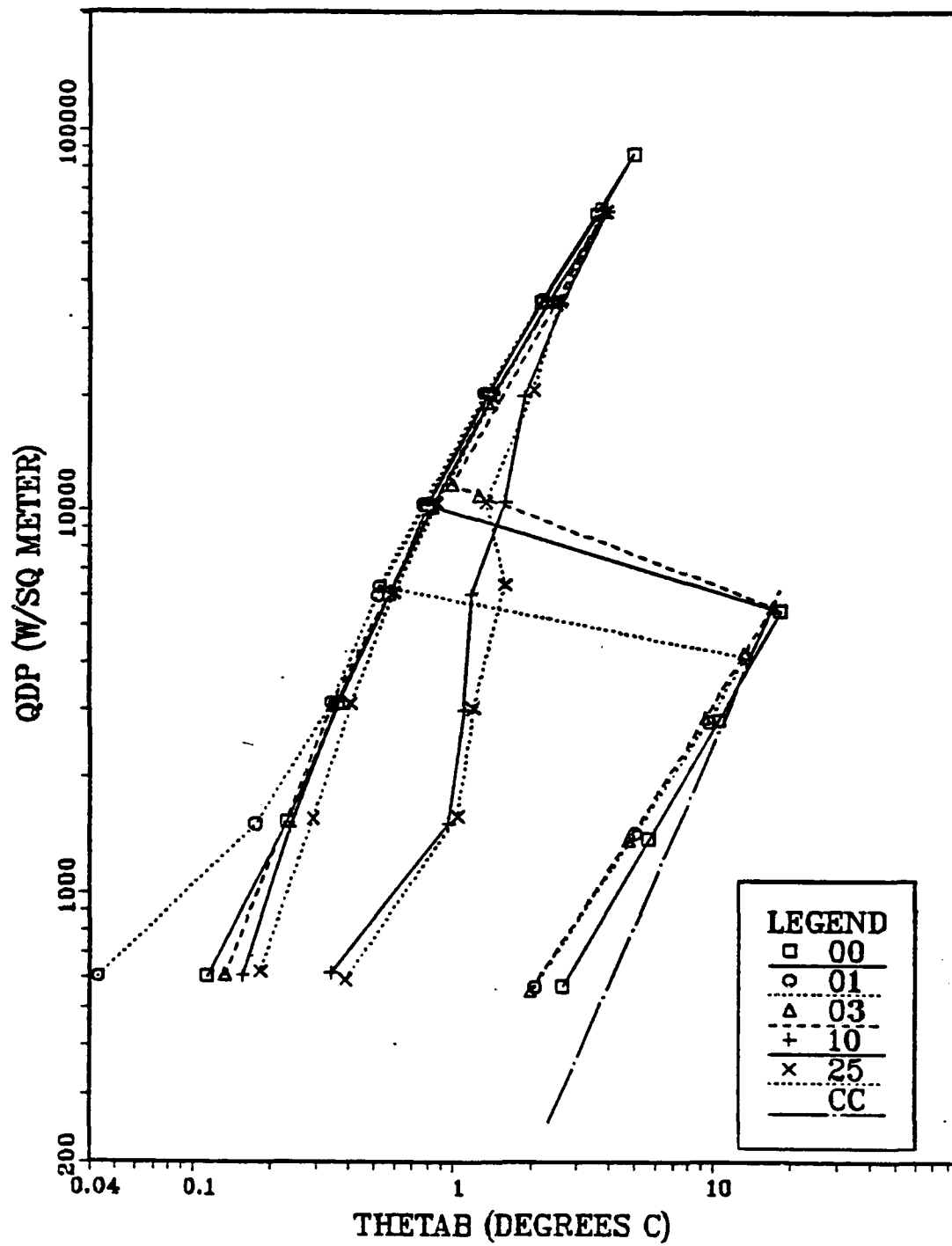


Figure 16. Comparison of Lower Tube Flux Settings for a p/d Ratio of 2 for High Flux Tube

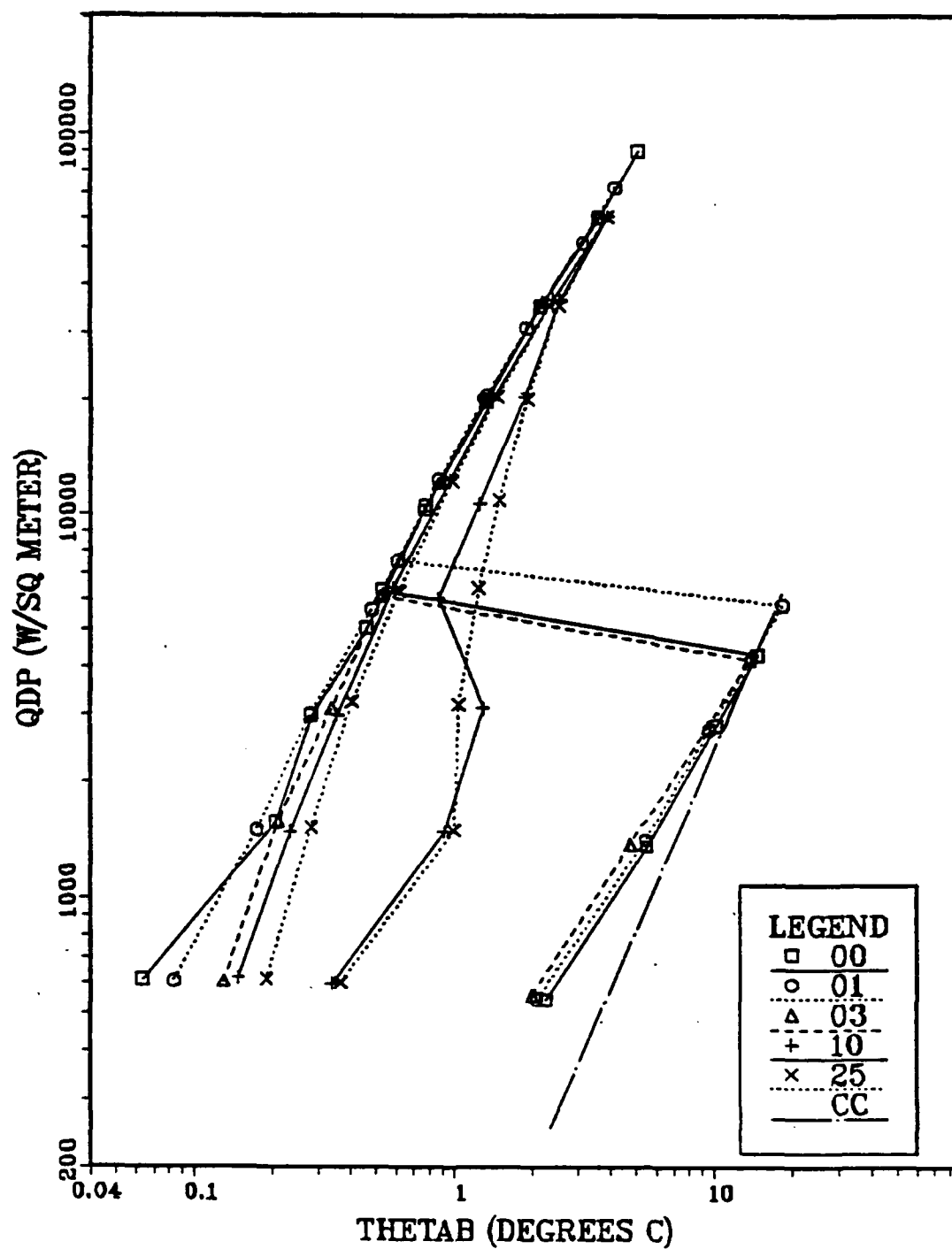


Figure 17. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.8 for High Flux Tube

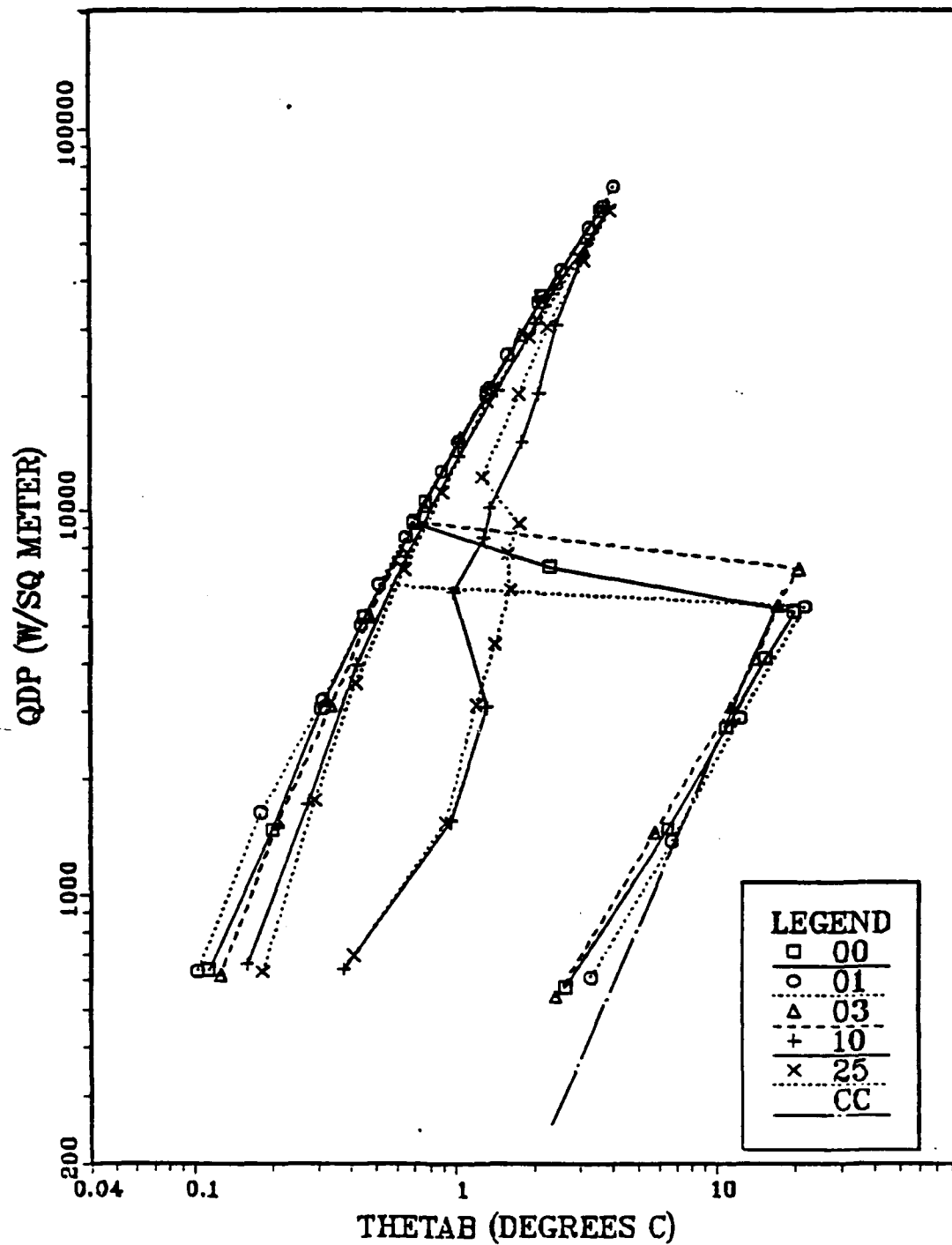


Figure 18. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.5 for High Flux Tube

values of p/d tested. This plot clearly shows the hysteresis loop for the smooth tubes (discussed earlier) and the earlier incipient point associated with the High Flux tubes. It should be noted that on a log/log plot, the temperature overshoot for the High Flux tubes looks much larger than that for the smooth tubes. In fact it is the other way around, with a smooth tube temperature overshoot of around 25 K and a High Flux value around 15 K. In the natural convection region, all the data fall very closely together. Following nucleation of the upper tube, the three curves for each tube jump to that tube's respective nucleate boiling curve for the remainder of the run; these curves agree well with Sugiyama's [Ref. 1] single tube data for both smooth and High Flux tubes. As expected for an unheated tube, there is no effect of tube spacing for High Flux tubes for any heat flux. However for the smooth tubes at high heat fluxes, there does appear to be a definite effect of tube spacing, with a p/d of 1.8 giving the best heat transfer performance. With the bottom tube unheated, it is unclear as to why this should be the case (except that its presence obviously effects the circulation patterns in the evaporator), but as will be seen, this trend is consistent even when the lower tube is heated.

b. Lower Tube Heat Flux Setting of 1 kW/m^2

Results for both tube surfaces at three values of p/d for a 1 kW/m^2 LTHFS are shown in Figure 20. In the natural convection region, it appears that both High Flux and smooth tubes show a small increasing enhancement with increasing tube spacing. This agrees with Sparrow and Niethammers [Ref. 11] and Marsters [Ref. 12] work with air. It should be noted that for this LTHFS, both upper and lower tube were in the convection region at the start of the increasing run. Figure 20 also shows the lower nucleation heat fluxes associated with ONB for High Flux tubes. Once the upper tubes nucleate, all curves 'jump' to a nucleate boiling curve. The High Flux tubes follow the same nucleate boiling curve regardless of spacing for the remainder of the run. This suggests that for a High Flux tube which is nucleating, there is no effect of heating from a lower tube with a LTHFS of 1 kW/m^2 or less for any p/d ratio. The smooth tubes on the other hand, do show small enhancements throughout the nucleate region for the three values of p/d . These are similar to the data shown in Figure 19 when the bottom tube was present but not heated, and suggests that these effects are directly related to the tube spacing itself and not due to the fact that the lower tube is heated. In Figure 20, there does seem to be some effect of p/d at these lower heat fluxes on the boiling curve; furthermore, this appears to be opposite to the trend found at high heat fluxes, i.e. a p/d of 1.5 gives the best heat transfer. However, this is thought to be ex-

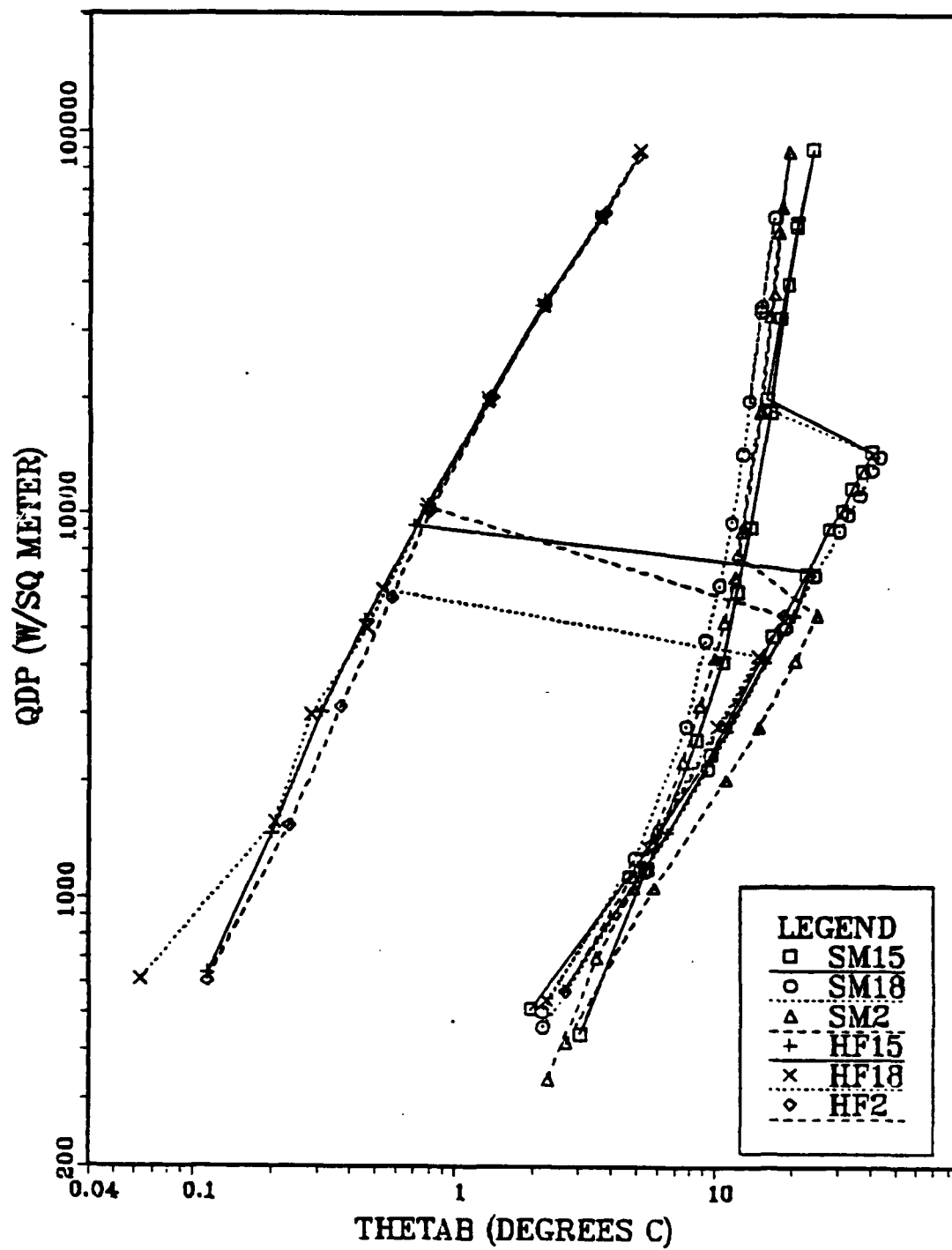


Figure 19. Comparison of Pitches for a Lower Tube Heat Flux Setting of 0 kW/m^2

perimental scatter as it does not occur on later graphs, whereas the effect at high heat fluxes is very repeatable.

c. Lower Tube Heat Flux Setting of 3 kW/m^2

The plot shown in Figure 21 for a LTHFS of 3 kW/m^2 is very similar to that for 1 kW/m^2 . The same enhancement trends are seen in the convection region in that both tubes show increasing enhancement with increasing pitch, with the exception of the smooth tube with a p/d of 1.8. This is believed to be due to scatter because the performance shown for both tubes for the other LTHFS

in the natural convection regime tend to follow an increasing enhancement with pitch trend. It should be noted for this LTHFS that both lower and upper tube were in the convection region at the beginning of the increasing run. Once the upper tube had nucleated, then the lower tube also started to nucleate from the 'seeding' process mentioned earlier. Following nucleation, the High Flux runs show the same results as in the previous LTHFS. The smooth tube still shows small enhancements at high heat fluxes as in the previous LTHFS, with a pitch of 1.8 giving the best enhancement. However in the boiling region below 10 kW/m^2 , no enhancements are discernable due to p/d (as mentioned earlier) and the curves fall directly on top of one another.

d. Lower Tube Heat Flux Setting of 10 kW/m^2

It should be noted that for this LTHFS, the lower tube nucleated at the beginning of the run and remained that way throughout the run. The plot for a LTHFS of 10 kW/m^2 is shown in Figure 22 and clearly shows the elimination of hysteresis for the smooth tube. Thus the effect of the bubbles from the lower tube sweeping over the upper tube (even when the upper tube is in the convection region) is enough to 'simulate' full nucleation from the upper tube, again supporting Cornwell's hypothesis that at low heat fluxes, the majority of the heat transfer from upper tubes in a bundle is due to convection effects from below. Figure 22 also clearly shows that there is no effect of spacing for smooth tubes except at high heat fluxes, as before (above 20 kW/m^2). For the High Flux tube it is clear that there is no effect of spacing in the decreasing portion of the curve as before. It is unclear what influence spacing may have on the increasing curve as any effects appear quite random. This suggests that the effect of spacing in this region is very small if not negligible. As mentioned earlier, the segment of the increasing High Flux curve between 500 and 1000 W/m^2 is parallel and very close to the same segment for the smooth tube curve. Note that for the smooth tube, the curve is the same for increasing and decreasing heat flux, suggesting that the top tube is not nucleating at these low heat fluxes and that the enhancement seen is due entirely to the sweeping

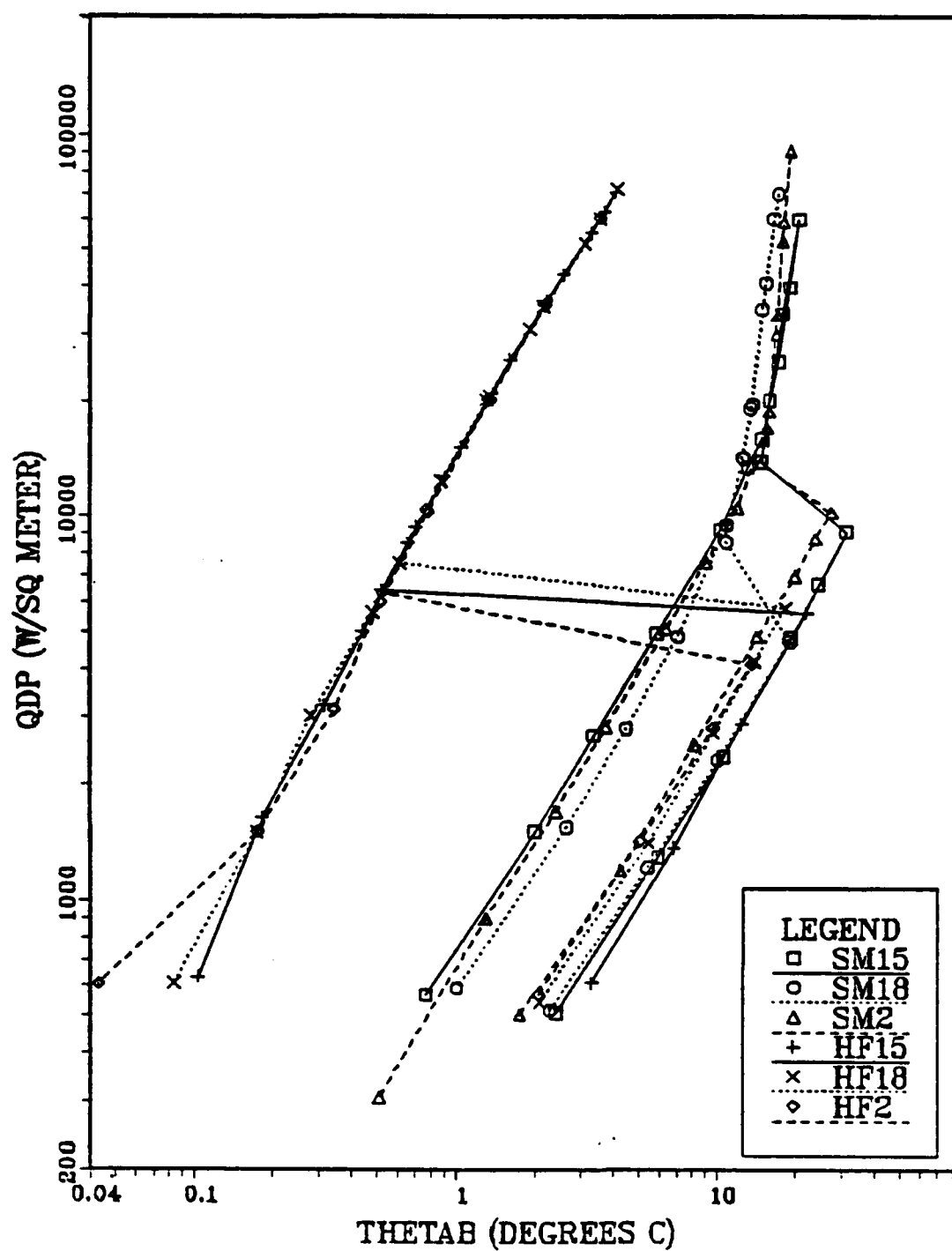


Figure 20. Comparison of Pitches for a Lower Tube Heat Flux Setting of 1 kW/m^2

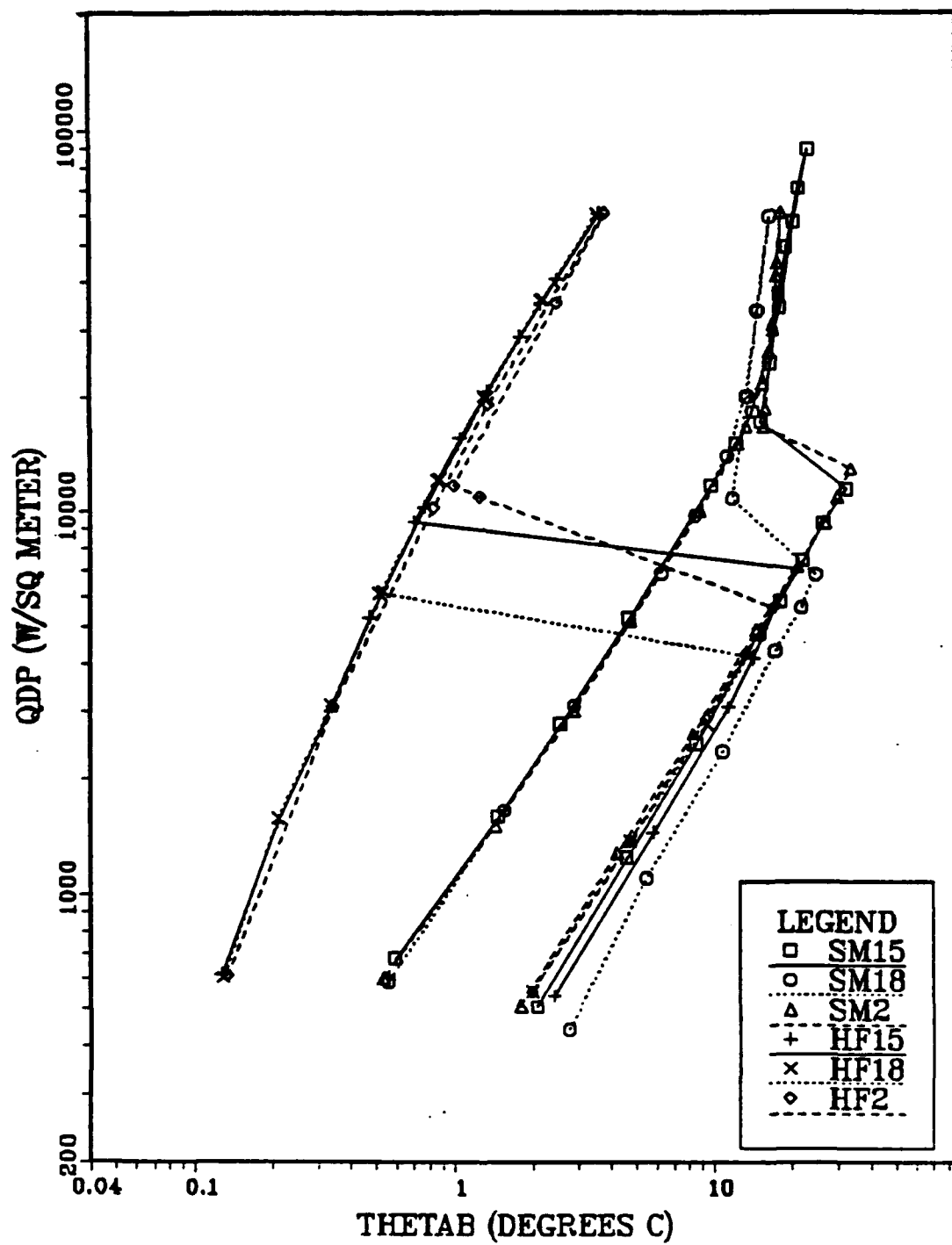


Figure 21. Comparison of Pitches for a Lower Tube Heat Flux Setting of 3 kW/m^2

bubbles from below. This implies that both tubes experience very similar convective effects when influenced by a vigorously boiling tube below. This was discussed in more detail earlier.

e. Lower Tube Heat Flux Setting of 25 kW/m^2

Figure 23 shows results for a LTHFS of 25 kW/m^2 and is very similar to that for 10 kW/m^2 . It should be noted that the lower tube in each case was nucleating from the beginning of the run. The only region where spacing has any effect is in the high heat flux boiling region (above 20 kW/m^2) for the smooth tube. As in the previous case, any effects of tube spacing on the High Flux tube can be considered negligible. Again, of particular interest is the segment of the increasing curves between 500 and 1000 W/m^2 . Here the curves for the smooth and High Flux tube fall on top of one another, further implying that at low heat fluxes (with the lower tube nucleating vigorously) the convection effects on the two types of surface are the same. Of note is the excellent repeatability of the data.

3. Both Tubes Subject To the Same Heat Flux

In addition to the data already presented, two additional runs were conducted, (one for each type of tube) in which the upper and lower tube were run up and down together at the same heat flux setting; these tests were both conducted with a p/d of 2. It should be noted that the upper and lower tubes were in the convection region at the beginning of the runs. The results of these two tests (for the upper tube only) are shown in Figure 24. The High Flux tube data fall on top of previous data, showing no effect of the lower tube throughout the entire heat flux range. This was expected due to the 'repeatability' of the High Flux tube shown in Figure 19 through Figure 23. The smooth tube shows a much earlier incipient heat flux for the upper tube. However, there is a large step in heat flux at this point due to the upper tube suddenly nucleating at a lower than expected heat flux (the cause of this nucleation is unknown and may be just a function of the randomness of this phenomenon mentioned earlier). Apart from its early ONB, the smooth tube follows a very similar boiling curve to that shown previously for a p/d of 2. At the lowest values of heat flux, the hysteresis 'loop' is still slightly open; this is because the lower tube still has a small number of active nucleation sites which are slightly enhancing the top tube. At 1 &capflux. , the difference between the increasing and decreasing values of ΔT is similar to that found on Figure 20 for a LTHFS of 1 kW/m^2 . This also true for the other LTHFS, i.e. the curve on Figure 24 coincides at one point with the boiling curves in Figure 19 through Figure 23 at the respective LTHFS. Of particular interest is that the foregoing results agree with and

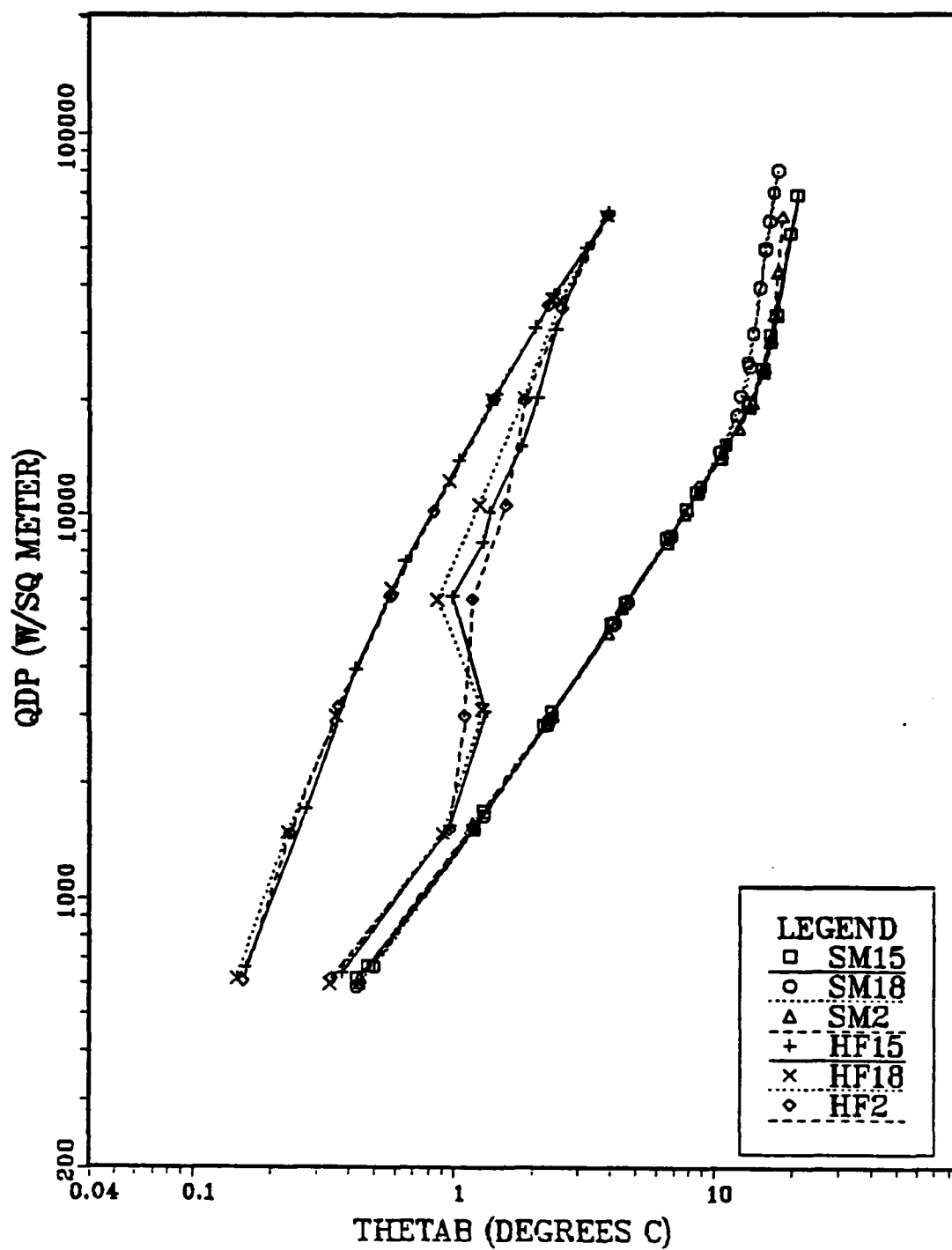


Figure 22. Comparison of Pitches for a Lower Tube Heat Flux Setting of 10 kW/m^2

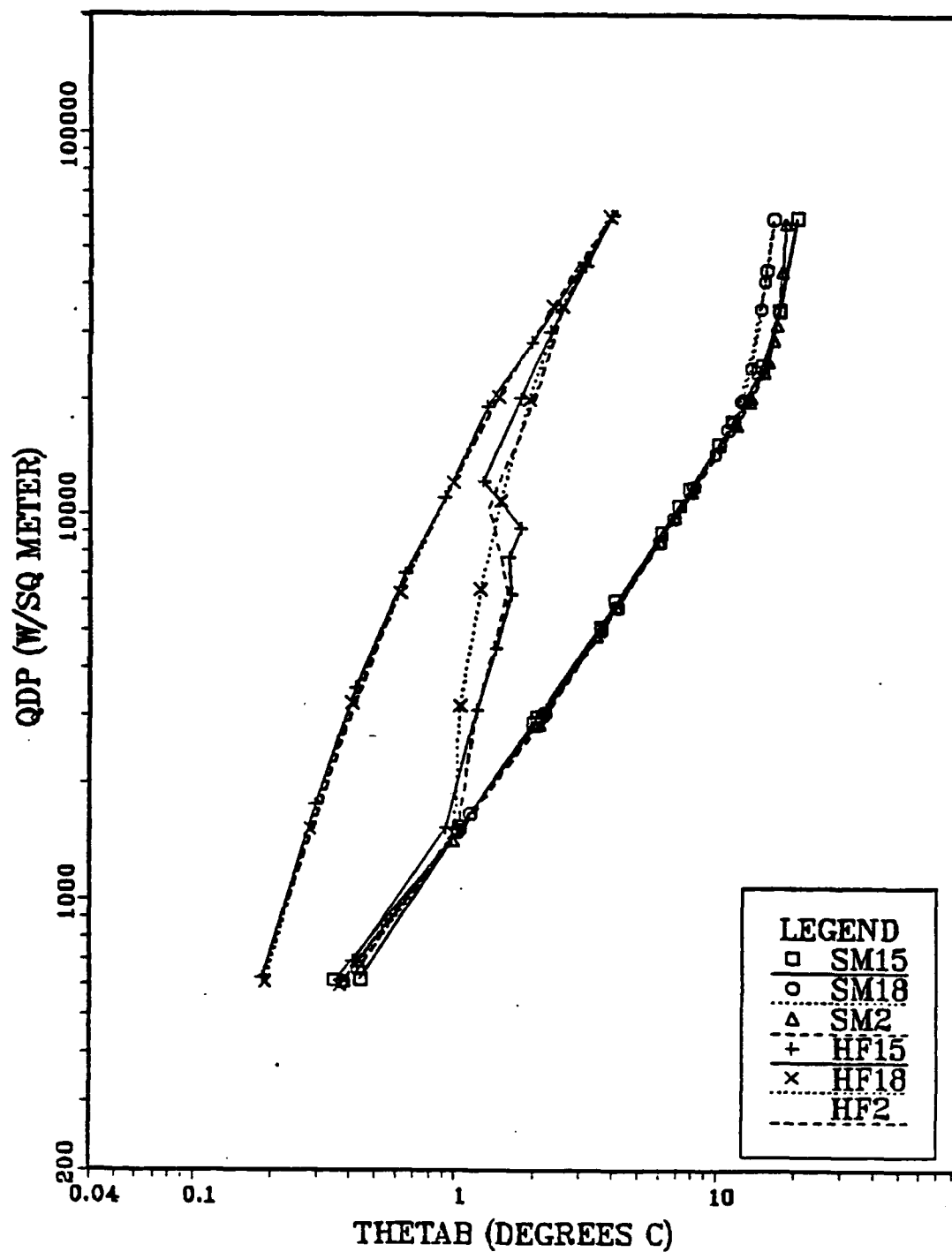


Figure 23. Comparison of Pitches for a Lower Tube Heat Flux Setting of 25 kW/m^2

complement certain results found from the bundle apparatus in the Heat Transfer laboratory. Not too many conclusions can be drawn from Figure 24 due to the lack of data taken at other spacings. This is one area which should be further investigated in the future.

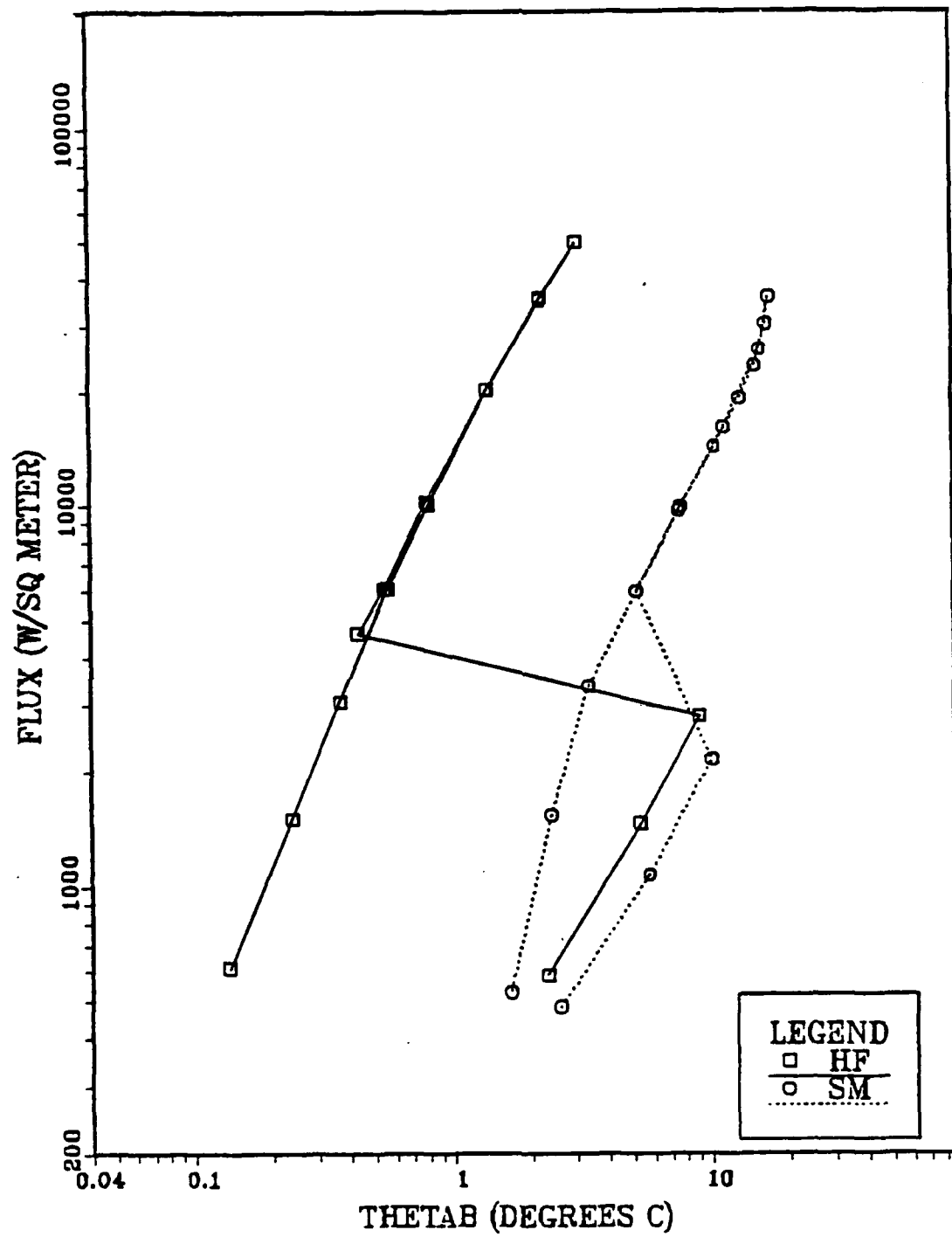


Figure 24. Comparison of Upper and Lower Tube Run Together

VI. CONCLUSIONS

1. There is no effect of tube spacing on High Flux tube performance at any heat flux.
2. The effect of tube spacing on smooth tube performance is present (but small) in the convection region. At high fluxes ($> 20 \text{ kW/m}^2$), there is a systematic dependence on tube spacing with a p/d ratio of 1.8 giving the best heat transfer performance.
3. A nucleating lower High Flux tube significantly enhances an upper High Flux tube in the convection region due to bubble sweeping. There is no effect of a heated lower tube on a nucleating upper High Flux tube.
4. A vigorously nucleating lower smooth tube ($> 10 \text{ kW/m}^2$) eliminates all hysteresis effects on an upper tube. A partially nucleating lower smooth tube ($\leq 3 \text{ kW/m}^2$) significantly enhances (by an order of magnitude) an upper smooth tube.
5. For low upper tube heat flux settings ($< 1000 \text{ W/m}^2$) and vigorous nucleation on the lower tube, High Flux and smooth tubes exhibited similar performance demonstrating that the majority of the heat transfer is due to bubble sweeping from below.

VII. RECOMMENDATIONS

1. Continue present work with other spacings and 'bundle' configurations.
2. Adapt the current apparatus to provide a larger evaporator to accommodate more than two tubes. This would probably also provide better conditions for videotaping the phenomena within the evaporator.
3. Resume experiments operating both tubes at the same heat fluxes for other spacings.
4. Pursue modeling of the enhancement effect, taking into account the mixed effects of convection (from a lower tube). Studies of a smooth tube placed above an enhanced tube might shed light on this.
5. Measurement of temperature in the plume from the lower tube to study the effect of spacing in both the natural convection and boiling region.
6. Acquisition of a Hewlett-Packard to IBM converter would greatly increase the ability to produce results from processed data within a short time frame.

APPENDIX A. SAMPLE CALCULATIONS

Data set DAT0529I52 was chosen for sample calculations. The saturation temperature was 2.25 °C, the heat flux on the upper tube was 35590 W/m^2 .

A. TEST-TUBE DIMENSIONS

$$D_o = 0.01582 \text{ m}$$

$$D_i = 0.0132 \text{ m}$$

$$D_1 = 0.013 \text{ m}$$

$$L = 0.190 \text{ m}$$

$$L_u = 0.076 \text{ m}$$

B. MEASURED PARAMETERS

$$V = 147.55 \text{ V}$$

$$I = 2.44 \text{ A}$$

$$T_1 = 5.88 \text{ }^{\circ}\text{C}$$

$$T_2 = 4.90 \text{ }^{\circ}\text{C}$$

$$T_3 = 5.38 \text{ }^{\circ}\text{C}$$

T_4 not read, defective

$$T_5 = 5.77 \text{ }^{\circ}\text{C}$$

$$T_6 = 7.06 \text{ }^{\circ}\text{C}$$

$$T7 = 5.66^{\circ}C$$

$$T8 = 5.48^{\circ}C$$

$$T_{sat} = 2.25^{\circ}C$$

$$k_c = 45 \text{ W/m} \cdot K$$

C. OUTER WALL TEMPERATURE OF THE TEST TUBE

$$p = \pi \cdot D_o = \pi \cdot 0.01582 = 0.0497 \text{ m}$$

$$A_c = \pi(D_o^2 - D_i^2)/4 = \pi\{(0.01582)^2 - (0.0132)^2\}/4$$

$$A_c = 5.97 \times 10^{-5} \text{ m}^2$$

$$Q_h = VI = 145.55 \cdot 2.44 = 360.02 \text{ W}$$

$$T_{avg} = \frac{\sum T_n}{m} = 5.73^{\circ}C$$

where m = the number of operational thermocouples used

$$T_{wo} = T_{avg} - Q_h \cdot \{ \ln(D_o/D_i) / (2 \cdot \pi \cdot L \cdot k_c) \}$$

$$T_{wo} = 5.73 - 360.02 \{ \ln(\frac{0.01582}{0.01295}) / (2 \cdot \pi \cdot 0.2032 \cdot 45) \}$$

$$T_{wo} = 4.48^{\circ}C$$

$$\Theta = T_{wo} - T_{sat} = 4.48 - 2.25 = 2.23^{\circ}C$$

D. PROPERTIES OF R-114 AT FILM TEMPERATURE

$$T_f = (T_{wo} + T_{sat})/2 = (4.48 + 2.25)/2 = 3.36 \text{ } ^\circ\text{C}$$

$$\mu = \exp[-4.4636 + (1011.47/T_f)] \cdot 10^{-3}$$

$$\mu = \exp[-4.4636 + (1011.47/(3.36 + 273.15))] \cdot 10^{-3} = 3.76 \times 10^{-4} \text{ N} \cdot \text{s}/\text{m}^2$$

$$T_c = \text{Critical Temperature}(^\circ\text{R}) = 753.95 \text{ } ^\circ\text{R}$$

$$T_f(^\circ\text{R}) = 498.05 \text{ } ^\circ\text{R}$$

$$j = 1 - T_f(R)/T_c(R) = 1 - 498.05/753.95 = 0.34$$

$$\rho = 581.77 + 984.15j^{1/3} + 263.02j + 279.99j^{1/2} + 17.94j^2$$

$$\rho = 1522.7 \text{ kg}/\text{m}^3$$

$$\nu = \mu/\rho = 3.7605 \times 10^{-4}/1522.72 = 2.47 \times 10^{-7} \text{ m}^2/\text{s}$$

$$k = 7.1 \times 10^{-2} - \{2.61 \times 10^{-4} \cdot T_f(^\circ\text{C})\}$$

$$k = 7.1 \times 10^{-2} - (2.61 \times 10^{-4} \cdot 3.36) = 7.01 \times 10^{-2} \text{ W}/\text{m} \cdot \text{K}$$

$$C_p = 400 + 1.65 \cdot T_f + (1.51 \times 10^{-3} \cdot T_f^2) - (6.68 \times 10^{-7} \cdot T_f^3)$$

$$C_p = 959.86 \text{ J}/\text{kg} \cdot \text{K}$$

$$\alpha = k/\rho \cdot C_p = 7.0224 \times \frac{10^{-2}}{1522.72 \cdot 959.856} = 4.80 \times 10^{-8} \text{ m}^2/\text{s}$$

$$\beta = -(\Delta\rho/\Delta T)/\rho = 1.02011 \times 10^{-3} (1/K)$$

$$Pr = \nu/\alpha = 5.15$$

E. HEAT FLUX CALCULATION

Using Churchill and Chu's correlation for a cylinder in natural convection, the heat transfer coefficient from one non-boiling end can be calculated as:

$$h = \frac{k}{Do} \left[0.6 + 0.387 \left\{ \frac{\left(\frac{g \cdot B \cdot Do^3 \cdot \Theta \cdot \tanh(m \cdot Lu)}{\nu \cdot \alpha \cdot Lu \cdot m} \right)^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}} \right\}^2 \right]$$

where

$$m = \{(h \cdot p)/(kc \cdot Ac)\}^{1/2}$$

and h was computed through an iterative process beginning with an assumed h of $190 \text{ W/m}^2 \cdot \text{K}$. The resulting h and m were:

$$h = 110.78 \text{ W/m}^2 \cdot \text{K}$$

$$m = 45.28$$

$$Q_f = (h \cdot p \cdot kc \cdot Ac)^{1/2} \cdot \Theta \cdot \tanh(m \cdot Lu) = 0.27 \text{ W}$$

F. HEAT FLUX THROUGH ACTIVE BOILING SURFACE

$$Q = Q_h - 2 \cdot Q_f = 360.02 - 2(0.27) = 359.47 \text{ W}$$

$$Ab = \pi \cdot Do \cdot L = \pi \cdot 0.01582 \cdot 0.2032 = 1.01 \times 10^{-2} \text{ m}^2$$

$$\dot{q} = Q/Ab = 359.47/1.01 \times 10^{-2} = 35595 \text{ W/m}^2$$

$$h = \dot{q}/\Theta = 35595/2.23 = 15955 \text{ W/m}^2 \cdot \text{K}$$

The following results were produced by the data acquisition and reduction program
DRP72:

$$\dot{q} = 35590 \text{ W/m}^2$$

$$h = 15969 \text{ W/m}^2 \cdot \text{K}$$

$$\Theta = 2.23 \text{ }^\circ\text{C}$$

The calculations were exactly the same for both tubes.

APPENDIX B. UNCERTAINTY ANALYSIS

For comparison purposes, uncertainty was determined using the same methods (those of Kline and McClintock [Ref. 18]) as Sugiyama in single tube work [Ref. 1 Appendix E]. Four data points (two for the smooth tube and two for the High Flux tube) were selected for the uncertainty analysis. These points were selected such that uncertainty could be determined in the high and low heat flux regions for each tube. The points selected were data sets 19 and 35 from run DAT0529D52 and data sets 1 and 13 from run DAT0425D42. The following is a sample calculation of uncertainty for data set 19 of run DAT0529D52 (i.e. low heat flux setting on the High Flux tube). Measured and calculated parameters were obtained as in Appendix A, sample calculations. *All uncertainties are expressed as a percentage of the calculated parameter.* Results are shown in Table 5

A. UNCERTAINTY IN INPUT POWER.

$$Qh = VI$$

$$I_s = 0.37 \text{ V} \quad \delta I = \pm 0.025 \text{ A}$$

where δ = uncertainty in measurement and calculation

$$V_s = 1.75 \text{ V} \quad \delta V = \pm 0.05 \text{ V}$$

$$I = 1.92 \cdot I_s = 0.71 \text{ A}$$

$$V = 25 \cdot V_s = 43.78 \text{ V}$$

$$\delta Qh/Qh = ((\delta V/V_s)^2 + (\delta I/I_s)^2)^{1/2}$$

$$\delta Qh/Qh = ((0.05/1.75)^2 + (0.025/0.37)^2)^{1/2}$$

$$\delta Qh/Qh = 7.33$$

B. UNCERTAINTY IN SURFACE AREA

$$Ab = \pi \cdot Do \cdot L$$

$$Do = 15.82mm \quad \delta Do = 0.1mm$$

$$L = 203.20mm \quad \delta L = 0.1mm$$

$$\delta Ab/Ab = ((\delta Do/Do)^2 + (\delta L/L)^2)^{1/2}$$

$$\delta Ab/Ab = ((0.1/15.82)^2 + (0.1/203.2)^2)^{1/2}$$

$$\delta Ab/Ab = 0.63$$

C. UNCERTAINTY IN WALL SUPERHEAT

$$\Delta T = T_{wo} - T_{sat}$$

$$T_{sat} = 2.27^\circ C \quad \delta T_{sat} = 0.01^\circ C$$

$$T_{wo} = T_{avg} - Qh[(\ln(Do/D1))/(2 \cdot \pi \cdot L \cdot kc)]$$

T_n = thermocouple readings

$$T1 = 2.76^\circ C \quad T2 = 2.61^\circ C$$

$$T3 = 2.67^\circ C \quad T4(\text{defective thermocouple})$$

$$T5 = 2.74^\circ C \quad T6 = 2.81^\circ C$$

$$T7 = 2.76^\circ C \quad T8 = 2.74^\circ C$$

$$T_{avg} = (\sum T_n/7)$$

where $n = 1$ to 3 , 5 to 8

$$T_{avg} = 2.73^{\circ}C$$

$$S.D. = ((\sum(T_n - T_{avg})^2)/n)^{1/2} = 0.061^{\circ}C$$

where S.D. = standard deviation

Compared to T_{avg} , the logarithmic term in the equation for T_{wo} is small and is neglected for the uncertainty analysis.

$$T_{wo} = T_{avg} = 2.73^{\circ}C \quad \delta T_{wo} = S.D. = 0.061^{\circ}C$$

$$\Delta T = 0.37^{\circ}C$$

$$\delta \Delta T / \Delta T = ((\delta T_{wo} / \Delta T)^2 + (\delta T_{sat} / \Delta T)^2)^{1/2}$$

$$\delta \Delta T / \Delta T = ((0.061 / 0.368)^2 + (0.01 / 0.368)^2)^{1/2}$$

$$\delta \Delta T / \Delta T = 16.8$$

D. UNCERTAINTY IN HEAT FLUX

$$\dot{q} = (Q_h - 2 \cdot Q_f) / A_b$$

$$Q_h = 31.08 W \quad \delta Q_h = 2.28 W$$

Assuming the same proportion in the uncertainty for Q_f (losses from the unheated ends):

$$Q_f = 1.6 W \quad \delta Q_f = 0.12 W$$

$$Q_h - 2 \cdot Q_f = 27.9 W$$

$$\delta \dot{q} / \dot{q} = \{(\delta Q_h / (Q_h - 2 \cdot Q_f))^2 + (2 \cdot Q_f / (Q_h - 2 \cdot Q_f))^2 + (\delta A_b / A_b)^2\}^{1/2}$$

$$\delta \dot{q}/\dot{q} = \{(2.28/27.88)^2 + (2 \cdot 0.12/27.88)^2 + (0.0063)^2\}^{1/2}$$

$$\delta \dot{q}/\dot{q} = 8.21$$

E. UNCERTAINTY IN BOILING HEAT TRANSFER COEFFICIENT

$$h = \dot{q}/\Delta T$$

$$\delta h/h = \{(\delta \dot{q}/\dot{q})^2 + (\delta \Delta T/\Delta T)^2\}^{1/2}$$

$$\delta h/h = \{(0.0821)^2 + (0.168)^2\}^{1/2}$$

$$\delta h/h = 18.7$$

Table 5. UNCERTAINTY ANALYSIS FOR FOUR POINTS

Parameters	Smooth tube 2685 W/m ²	Smooth tube 38440 W/m ²	High Flux tube 3070 W/m ²	High Flux tube 35590 W/m ²
$\delta Qh/Qh$ (%)	7.01	1.98	7.33	2.14
$\delta Ab/Ab$ (%)	0.63	0.63	0.63	0.63
$\delta \Delta T/\Delta T$ (%)	1.91	2.52	16.8	8.08
$\delta \dot{q}/\dot{q}$ (%)	7.79	2.18	8.21	2.23
$\delta h/h$ (%)	8.02	3.33	18.7	9.40

Uncertainties listed in Table 5 show that the main source of uncertainty is in the measurement and calculation of ΔT . The uncertainty in ΔT is probably due to inaccuracies introduced during the manufacturing process. For instance, the solder pools attaching thermocouple wires to the interior sleeve may have impurities (e.g. small air gaps) which in close proximity to the thermocouple junction could affect the local heat resistance and thereby the temperature. Eight thermocouples were used to obtain the wall average and reduce this uncertainty. This also points out that further improvements in accuracy must be made in this area first. Graphical displays of uncertainty are shown in Figure 10 and Figure 11.

APPENDIX C. REPRESENTATIVE DATA SET

Date : 6 Apr 1992

NOTE: Program name : DRP72
Disk number = 00
New file name: DAT0406I42
TC is defective at location 5
No defective AUX TCs exist
Tube Number: 4

Data Set Number = 1 Bulk Oil % = 0.0
TIME: 16:09:03
TC No: 1 2 3 4 5 6 7 8
Temp : 2.61 2.62 2.64 2.62 -99.99 2.61 2.62 2.66
TC No: 9 10 11 12 13 14 15 16
Temp : 16.87 27.84 22.11 26.61 10.17 27.90 18.51 23.24
Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
2.62 21.59 2.28 2.21 2.28 -1.70 -16.5
Thetab Htube Qdp Athetab Ahtube AuQdp
.356 1.716E+03 6.112E+02 19.325 5.093E+02 9.842E+03

Data Set Number = 2 Bulk Oil % = 0.0
TIME: 16:10:51
TC No: 1 2 3 4 5 6 7 8
Temp : 2.71 2.72 2.73 2.70 -99.99 2.68 2.68 2.73
TC No: 9 10 11 12 13 14 15 16
Temp : 16.87 27.86 22.10 26.60 10.15 27.89 18.46 23.21
Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
2.70 21.58 2.31 2.24 2.26 -1.69 -16.5
Thetab Htube Qdp Athetab Ahtube AuQdp
.437 1.384E+03 6.048E+02 19.309 5.074E+02 9.798E+03

Data Set Number = 3 Bulk Oil % = 0.0
TIME: 16:15:44
TC No: 1 2 3 4 5 6 7 8
Temp : 3.42 3.50 3.49 3.47 -99.99 3.40 3.40 3.52
TC No: 9 10 11 12 13 14 15 16
Temp : 16.86 27.86 22.07 26.63 10.08 27.94 18.50 23.25
Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
3.45 21.58 2.28 2.21 2.24 -1.72 -16.4
Thetab Htube Qdp Athetab Ahtube AuQdp
1.206 1.307E+03 1.577E+03 19.342 5.100E+02 9.864E+03

Data Set Number = 4 Bulk Oil % = 0.0
TIME: 16:16:21
TC No: 1 2 3 4 5 6 7 8
Temp : 3.43 3.52 3.51 3.48 -99.99 3.40 3.40 3.54
TC No: 9 10 11 12 13 14 15 16
Temp : 16.87 27.85 22.07 26.62 10.12 27.93 18.51 23.24
Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
3.46 21.59 2.31 2.22 2.27 -1.69 -16.4
Thetab Htube Qdp Athetab Ahtube AuQdp
1.189 1.324E+03 1.574E+03 19.314 5.106E+02 9.862E+03

Data Set Number = 5 Bulk Oil % = 0.0
TIME: 16:22:00
TC No: 1 2 3 4 5 6 7 8
Temp : 4.47 4.66 4.64 4.60 -99.99 4.45 4.44 4.65
TC No: 9 10 11 12 13 14 15 16

Temp : 16.92 27.79 21.99 26.55 10.08 27.86 18.44 23.18
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 4.54 21.52 2.25 2.18 2.23 -1.74 -16.3
 Thetab Htube Qdp Athetab Ahtube AuQdp
 2.321 1.270E+03 2.948E+03 19.301 5.106E+02 9.855E+03

Data Set Number = 6 Bulk Oil % = 0.0

TIME: 16:22:41
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.51 4.65 4.62 4.57 -99.99 4.45 4.44 4.64
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.81 27.78 21.98 26.55 10.06 27.86 18.45 23.17
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 4.54 21.52 2.29 2.19 2.23 -1.73 -16.2
 Thetab Htube Qdp Athetab Ahtube AuQdp
 2.305 1.279E+03 2.948E+03 19.283 5.116E+02 9.865E+03

Data Set Number = 7 Bulk Oil % = 0.0

TIME: 16:27:34
 TC No: 1 2 3 4 5 6 7 8
 Temp : 6.63 6.95 6.89 6.82 -99.99 6.48 6.48 6.90
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.79 27.80 21.97 26.57 10.00 27.88 18.43 23.19
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 6.70 21.51 2.27 2.19 2.20 -1.75 -16.2
 Thetab Htube Qdp Athetab Ahtube AuQdp
 4.484 1.269E+03 5.689E+03 19.296 5.113E+02 9.867E+03

Data Set Number = 8 Bulk Oil % = 0.0

TIME: 16:28:36
 TC No: 1 2 3 4 5 6 7 8
 Temp : 6.58 6.95 6.89 6.81 -99.99 6.55 6.55 6.95
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.89 27.88 22.06 26.65 10.20 27.96 18.54 23.27
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 6.72 21.61 2.30 2.26 2.32 -1.66 -16.1
 Thetab Htube Qdp Athetab Ahtube AuQdp
 4.419 1.292E+03 5.709E+03 19.313 5.131E+02 9.909E+03

Data Set Number = 9 Bulk Oil % = 0.0

TIME: 16:30:19
 TC No: 1 2 3 4 5 6 7 8
 Temp : 6.64 6.99 6.94 6.86 -99.99 6.62 6.60 6.97
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.89 27.90 22.08 26.67 10.19 27.99 18.55 23.30
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 6.77 21.63 2.36 2.28 2.33 -1.63 -16.1
 Thetab Htube Qdp Athetab Ahtube AuQdp
 4.443 1.285E+03 5.710E+03 19.304 5.132E+02 9.906E+03

Data Set Number = 10 Bulk Oil % = 0.0

TIME: 16:36:47
 TC No: 1 2 3 4 5 6 7 8
 Temp : 8.57 9.15 9.03 8.95 -99.99 8.48 8.51 9.06
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.90 27.82 21.99 26.59 10.03 27.90 18.44 23.21
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 8.77 21.53 2.27 2.20 2.25 -1.72 -15.9
 Thetab Htube Qdp Athetab Ahtube AuQdp
 6.529 1.292E+03 8.431E+03 19.298 5.135E+02 9.904E+03

Data Set Number = 11 Bulk Oil % = 0.0
 TIME: 16:37:31
 TC No: 1 2 3 4 5 6 7 8
 Temp : 8.67 9.15 9.07 8.96 -99.99 8.57 8.54 9.04
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.93 27.85 22.01 26.61 10.04 27.93 18.48 23.24
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 -8.81 21.56 2.28 2.22 2.27 -1.71 -15.9
 Thetab Htube Qdp Athetab Ahtube AuQdp
 6.549 1.298E+03 8.433E+03 19.302 5.141E+02 9.924E+03

Data Set Number = 12 Bulk Oil % = 0.0
 TIME: 16:46:52
 TC No: 1 2 3 4 5 6 7 8
 Temp : 10.81 11.49 11.44 11.32 -99.99 10.67 10.70 11.45
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.85 27.92 22.03 26.67 10.02 28.00 18.49 23.28
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 11.06 21.59 2.32 2.26 2.28 -1.67 -15.5
 Thetab Htube Qdp Athetab Ahtube AuQdp
 8.771 1.314E+03 1.152E+04 19.305 5.152E+02 9.946E+03

Data Set Number = 13 Bulk Oil % = 0.0
 TIME: 16:47:44
 TC No: 1 2 3 4 5 6 7 8
 Temp : 10.76 11.52 11.44 11.21 -99.99 10.73 10.71 11.36
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.85 27.89 22.01 26.65 10.01 27.97 18.49 23.25
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 11.03 21.57 2.32 2.24 2.27 -1.68 -15.4
 Thetab Htube Qdp Athetab Ahtube AuQdp
 8.759 1.318E+03 1.154E+04 19.296 5.166E+02 9.969E+03

Data Set Number = 14 Bulk Oil % = 0.0
 TIME: 16:57:55
 TC No: 1 2 3 4 5 6 7 8
 Temp : 12.48 13.36 13.26 13.10 -99.99 12.29 12.30 13.19
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.80 27.91 21.99 26.66 9.97 27.99 18.45 23.25
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 12.77 21.56 2.23 2.18 2.18 -1.77 -14.9
 Thetab Htube Qdp Athetab Ahtube AuQdp
 10.576 1.332E+03 1.409E+04 19.366 5.158E+02 9.989E+03

Data Set Number = 15 Bulk Oil % = 0.0
 TIME: 16:58:31
 TC No: 1 2 3 4 5 6 7 8
 Temp : 12.40 13.36 13.29 13.14 -99.99 12.46 12.46 13.36
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.94 27.92 22.02 26.68 10.00 28.02 18.49 23.29
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 12.84 21.59 2.24 2.19 2.22 -1.74 -14.8
 Thetab Htube Qdp Athetab Ahtube AuQdp
 10.619 1.330E+03 1.412E+04 19.369 5.171E+02 1.002E+04

Data Set Number = 16 Bulk Oil % = 0.0
 TIME: 17:05:00
 TC No: 1 2 3 4 5 6 7 8
 Temp : 14.01 15.05 15.14 14.72 -99.99 14.13 14.08 15.06

TC No: 9 10 11 12 13 14 15 16
 Temp : 16.84 27.94 22.04 26.69 10.02 29.02 18.49 23.26
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 14.52 21.59 2.29 2.23 2.19 -1.74 -14.5
 Thetab Htube Qdp Athetab Ahtube AuQdp
 12.300 1.365E+03 1.679E+04 19.370 5.170E+02 1.001E+04

Data Set Number = 17 Bulk Oil % = 0.0

TIME: 17:05:42
 TC No: 1 2 3 4 5 6 7 8
 Temp : 14.12 15.39 15.28 14.77 -99.99 14.15 14.16 15.10
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.83 27.93 22.02 26.69 9.98 28.02 18.49 23.28
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 14.61 21.59 2.27 2.18 2.20 -1.75 -14.4
 Thetab Htube Qdp Athetab Ahtube AuQdp
 12.398 1.354E+03 1.679E+04 19.376 5.154E+02 9.986E+03

Data Set Number = 18 Bulk Oil % = 0.0

TIME: 17:10:46
 TC No: 1 2 3 4 5 6 7 8
 Temp : 15.54 16.91 16.80 16.36 -99.99 16.07 16.01 16.72
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.68 27.63 21.81 26.40 9.92 27.71 18.31 23.03
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 16.24 21.37 2.25 2.16 2.14 -1.80 -14.2
 Thetab Htube Qdp Athetab Ahtube AuQdp
 14.067 1.406E+03 1.978E+04 19.198 5.147E+02 9.881E+03

Data Set Number = 19 Bulk Oil % = 0.0

TIME: 17:11:22
 TC No: 1 2 3 4 5 6 7 8
 Temp : 15.54 16.84 16.73 16.36 -99.99 16.06 15.96 16.80
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.68 27.64 21.80 26.41 9.94 27.72 18.32 23.04
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 16.21 21.38 2.25 2.15 2.15 -1.80 -14.1
 Thetab Htube Qdp Athetab Ahtube AuQdp
 14.036 1.407E+03 1.975E+04 19.207 5.139E+02 9.870E+03

Data Set Number = 20 Bulk Oil % = 0.0

TIME: 17:16:58
 TC No: 1 2 3 4 5 6 7 8
 Temp : 17.40 18.39 18.23 17.64 -99.99 17.89 17.62 18.27
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.77 27.72 21.88 26.50 9.98 27.79 18.39 23.08
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 17.78 21.45 2.32 2.25 2.20 -1.72 -13.9
 Thetab Htube Qdp Athetab Ahtube AuQdp
 15.539 1.516E+03 2.355E+04 19.206 5.148E+02 9.986E+03

Data Set Number = 21 Bulk Oil % = 0.0

TIME: 17:17:40
 TC No: 1 2 3 4 5 6 7 8
 Temp : 17.39 18.33 18.18 17.62 -99.99 17.82 17.64 18.24
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.77 27.74 21.91 26.52 10.02 27.82 18.42 23.11
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 17.75 21.47 2.32 2.25 2.19 -1.73 -13.8
 Thetab Htube Qdp Athetab Ahtube AuQdp

15.511 1.522E+03 2.360E+04 19.234 5.159E+02 9.923E+03

Data Set Number = 22 Bulk Oil % = 0.0

TIME: 17:23:15

TC No:	1	2	3	4	5	6	7	8
Temp :	18.56	18.95	19.94	18.14	-99.99	19.66	18.75	18.83
TC No:	9	10	11	12	13	14	15	16
Temp :	16.77	27.73	21.90	26.50	10.07	27.81	18.40	23.11
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
18.65	21.47	2.28	2.25	2.12	-1.77	-13.5		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
16.455	1.725E+03	2.838E+04	19.274	5.138E+02	9.903E+03			

Data Set Number = 23 Bulk Oil % = 0.0

TIME: 17:23:57

TC No:	1	2	3	4	5	6	7	8
Temp :	18.50	18.93	18.88	18.11	-99.99	19.63	18.72	18.81
TC No:	9	10	11	12	13	14	15	16
Temp :	16.77	27.74	21.90	26.52	10.05	27.83	18.42	23.12
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
18.63	21.48	2.28	2.22	2.12	-1.78	-13.5		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
16.442	1.729E+03	2.843E+04	19.291	5.126E+02	9.889E+03			

Data Set Number = 24 Bulk Oil % = 0.0

TIME: 17:29:40

TC No:	1	2	3	4	5	6	7	8
Temp :	19.09	19.38	19.33	18.42	-99.99	21.01	19.60	19.18
TC No:	9	10	11	12	13	14	15	16
Temp :	16.83	27.80	21.96	26.58	10.09	27.87	18.47	23.14
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
19.23	21.53	2.29	2.18	2.17	-1.76	-13.1		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
17.029	1.969E+03	3.353E+04	19.320	5.122E+02	9.896E+03			

Data Set Number = 25 Bulk Oil % = 0.0

TIME: 17:30:27

TC No:	1	2	3	4	5	6	7	8
Temp :	19.10	19.42	19.32	18.42	-99.99	21.02	19.60	19.16
TC No:	9	10	11	12	13	14	15	16
Temp :	16.84	27.81	21.97	26.60	10.11	27.89	18.48	23.18
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
19.24	21.54	2.32	2.21	2.19	-1.74	-13.1		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
17.010	1.968E+03	3.348E+04	19.317	5.107E+02	9.865E+03			

Data Set Number = 26 Bulk Oil % = 0.0

TIME: 17:35:53

TC No:	1	2	3	4	5	6	7	8
Temp :	19.60	19.79	19.81	18.74	-99.99	22.75	20.47	19.48
TC No:	9	10	11	12	13	14	15	16
Temp :	16.81	27.76	21.93	26.54	10.06	27.83	18.44	23.13
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
19.84	21.49	2.21	2.10	2.11	-1.84	-12.7		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
17.705	2.449E+03	4.335E+04	19.361	5.096E+02	9.866E+03			

Data Set Number = 27 Bulk Oil % = 0.0

TIME: 17:36:50

TC No:	1	2	3	4	5	6	7	8
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Temp : 19.62 19.81 19.82 19.76 -99.99 22.76 20.54 19.53
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.97 27.80 21.98 26.58 10.18 27.88 18.51 23.18
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 19.87 21.55 2.33 2.19 2.20 -1.73 -12.6
 Thetab Htube Qdp Athetab Ahtube AuQdp
 17.639 2.456E+03 4.332E+04 19.326 5.110E+02 9.875E+03

Data Set Number = 28 Bulk Oil % = 0.0

TIME: 17:40:06
 TC No: 1 2 3 4 5 6 7 8
 Temp : 20.25 20.32 20.40 19.23 -99.99 24.53 21.18 20.00
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.89 27.83 21.99 26.60 10.17 27.91 18.53 23.22
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 20.50 21.58 2.32 2.28 2.14 -1.75 -12.3
 Thetab Htube Qdp Athetab Ahtube AuQdp
 18.277 3.312E+03 6.054E+04 19.359 5.083E+02 9.839E+03

Data Set Number = 29 Bulk Oil % = 0.0

TIME: 17:40:48
 TC No: 1 2 3 4 5 6 7 8
 Temp : 20.23 20.30 20.38 19.22 -99.99 24.51 21.17 20.00
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.85 27.74 21.93 26.51 10.13 27.82 18.47 23.15
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 20.48 21.51 2.33 2.25 2.16 -1.74 -12.2
 Thetab Htube Qdp Athetab Ahtube AuQdp
 18.254 3.306E+03 6.034E+04 19.283 5.096E+02 9.826E+03

Data Set Number = 30 Bulk Oil % = 0.0

TIME: 17:41:22
 TC No: 1 2 3 4 5 6 7 8
 Temp : 20.23 20.31 20.38 19.22 -99.99 24.51 21.17 20.00
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.86 27.77 21.95 26.55 10.14 27.85 18.50 23.16
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 20.48 21.53 2.30 2.27 2.13 -1.76 -12.2
 Thetab Htube Qdp Athetab Ahtube AuQdp
 18.275 3.310E+03 6.049E+04 19.323 5.100E+02 9.854E+03

NOTE: 29 data runs were stored in file DAT0406I42

Date : 6 Apr 1992

NOTE: Program name : DRP72
 Disk number = 00
 New file name: DAT0406D42
 TC is defective at location 5
 No defective AUX TCs exist
 Tube Number: 4

Data Set Number = 1 Bulk Oil % = 0.0

TIME: 17:48:16
 TC No: 1 2 3 4 5 6 7 8
 Temp : 19.64 19.85 19.85 19.76 -99.99 22.85 20.54 19.54
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.80 27.70 21.99 26.48 10.07 27.79 18.44 23.12
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 19.89 21.47 2.31 2.23 2.11 -1.78 -11.7

Thetab Htube Qdp Athetab Ahtube AuQdp
17.700 2.481E+03 4.392E+04 19.279 5.110E+02 9.850E+03

Data Set Number = 2 Bulk Oil % = 0.0

TIME: 17:49:07

TC No: 1 2 3 4 5 6 7 8
Temp : 19.64 19.88 19.88 18.78 -99.99 22.85 20.52 19.56
TC No: 9 10 11 12 13 14 15 16
Temp : 16.79 27.66 21.87 26.45 10.11 27.75 18.42 23.07

Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
19.90 21.45 2.32 2.28 2.14 -1.75 -11.7
Thetab Htube Qdp Athetab Ahtube AuQdp
17.685 2.476E+03 4.378E+04 19.231 5.112E+02 9.830E+03

Data Set Number = 3 Bulk Oil % = 0.0

TIME: 17:54:28

TC No: 1 2 3 4 5 6 7 8
Temp : 18.55 19.04 18.96 18.18 -99.99 19.76 18.77 18.87
TC No: 9 10 11 12 13 14 15 16
Temp : 16.70 27.60 21.79 26.38 9.99 27.68 18.33 23.09

Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
18.70 21.38 2.23 2.19 2.09 -1.82 -11.5
Thetab Htube Qdp Athetab Ahtube AuQdp
16.552 1.755E+03 2.905E+04 19.226 5.121E+02 9.845E+03

Data Set Number = 4 Bulk Oil % = 0.0

TIME: 17:55:10

TC No: 1 2 3 4 5 6 7 8
Temp : 18.61 19.05 18.96 18.17 -99.99 19.76 18.85 18.89
TC No: 9 10 11 12 13 14 15 16
Temp : 16.71 27.63 21.80 26.41 9.99 27.71 18.35 23.12

Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
18.73 21.40 2.26 2.20 2.12 -1.79 -11.5
Thetab Htube Qdp Athetab Ahtube AuQdp
16.551 1.756E+03 2.906E+04 19.222 5.122E+02 9.845E+03

Data Set Number = 5 Bulk Oil % = 0.0

TIME: 18:01:43

TC No: 1 2 3 4 5 6 7 8
Temp : 17.47 18.37 18.30 17.72 -99.99 17.94 17.61 18.35
TC No: 9 10 11 12 13 14 15 16
Temp : 16.70 27.60 21.78 26.39 9.96 27.67 18.32 23.07

Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
17.82 21.37 2.23 2.18 2.09 -1.83 -11.4
Thetab Htube Qdp Athetab Ahtube AuQdp
15.678 1.555E+03 2.439E+04 19.225 5.140E+02 9.882E+03

Data Set Number = 6 Bulk Oil % = 0.0

TIME: 18:02:25

TC No: 1 2 3 4 5 6 7 8
Temp : 17.49 18.30 18.25 17.75 -99.99 17.96 17.62 18.23
TC No: 9 10 11 12 13 14 15 16
Temp : 16.75 27.71 21.86 26.50 9.99 27.79 18.39 23.18

Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
17.80 21.45 2.25 2.22 2.10 -1.80 -11.4
Thetab Htube Qdp Athetab Ahtube AuQdp
15.627 1.562E+03 2.442E+04 19.295 5.153E+02 9.938E+03

Data Set Number = 7 Bulk Oil % = 0.0

TIME: 18:07:14

TC No: 1 2 3 4 5 6 7 8
 Temp : 15.29 16.40 16.31 15.94 -99.99 15.69 15.53 16.35
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.74 27.72 21.84 26.50 9.89 27.90 18.38 23.19
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 15.92 21.44 2.22 2.13 2.14 -1.81 -11.4
 Thetab Htube Qdp Athetab Ahtube AuQdp
 13.656 1.402E+03 1.915E+04 19.281 5.153E+02 9.937E+03

Data Set Number = 8 Bulk Oil % = 0.0

TIME: 18:07:50

TC No: 1 2 3 4 5 6 7 8
 Temp : 15.33 16.51 16.43 15.99 -99.99 15.59 15.55 16.40
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.75 27.73 21.97 26.50 9.94 27.81 18.39 23.20
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 15.86 21.46 2.23 2.16 2.14 -1.80 -11.4
 Thetab Htube Qdp Athetab Ahtube AuQdp
 13.690 1.397E+03 1.912E+04 19.290 5.138E+02 9.912E+03

Data Set Number = 9 Bulk Oil % = 0.0

TIME: 18:12:30

TC No: 1 2 3 4 5 6 7 8
 Temp : 12.40 13.42 13.33 13.03 -99.99 12.45 12.33 13.24
 TC No: 9 10 11 12 13 14 15 16
 Temp : 17.23 28.71 22.91 27.44 10.37 28.81 18.97 24.02
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 12.80 22.24 2.28 2.23 2.22 -1.73 -11.4
 Thetab Htube Qdp Athetab Ahtube AuQdp
 10.564 1.337E+03 1.412E+04 20.002 5.198E+02 1.040E+04

Data Set Number = 10 Bulk Oil % = 0.0

TIME: 18:13:45

TC No: 1 2 3 4 5 6 7 8
 Temp : 12.22 13.34 13.25 12.95 -99.99 12.41 12.41 13.25
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.92 27.94 22.25 26.62 10.12 27.93 18.48 23.31
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 12.75 21.60 2.27 2.18 2.20 -1.75 -11.4
 Thetab Htube Qdp Athetab Ahtube AuQdp
 10.536 1.340E+03 1.412E+04 19.392 5.143E+02 9.973E+03

Data Set Number = 11 Bulk Oil % = 0.0

TIME: 18:14:39

TC No: 1 2 3 4 5 6 7 8
 Temp : 12.33 13.31 13.25 12.95 -99.99 12.39 12.36 13.24
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.97 27.94 22.33 26.72 10.10 28.04 18.53 23.37
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 12.75 21.67 2.23 2.20 2.19 -1.76 -11.4
 Thetab Htube Qdp Athetab Ahtube AuQdp
 10.547 1.340E+03 1.413E+04 19.469 5.161E+02 1.005E+04

Data Set Number = 12 Bulk Oil % = 0.0

TIME: 18:15:27

TC No: 1 2 3 4 5 6 7 8
 Temp : 12.38 13.35 13.22 13.00 -99.99 12.49 12.49 13.19
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.63 27.45 21.92 26.21 9.39 27.50 18.16 22.96
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump

12.79	21.27	2.29	2.24	2.23	-1.72	-11.4
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp	
10.545	1.334E+03	1.406E+04	19.029	5.060E+02	9.628E+03	

Data Set Number = 13 Bulk Oil % = 0.0

TIME: 18:20:06

TC No:	1	2	3	4	5	6	7	8
Temp :	9.58	10.38	10.34	10.11	-99.99	9.65	9.65	10.23
TC No:	9	10	11	12	13	14	15	16
Temp :	16.51	27.11	21.70	25.94	9.92	27.19	18.05	22.71
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
9.93	21.08	2.25	2.19	2.21	-1.75	-11.5		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
7.718	1.297E+03	1.001E+04	18.862	5.090E+02	9.601E+03			

Data Set Number = 14 Bulk Oil % = 0.0

TIME: 18:20:40

TC No:	1	2	3	4	5	6	7	8
Temp :	9.64	10.30	10.21	9.96	-99.99	9.60	9.57	10.20
TC No:	9	10	11	12	13	14	15	16
Temp :	16.49	27.08	21.68	25.90	9.91	27.16	18.04	22.69
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
9.87	21.06	2.22	2.17	2.16	-1.79	-11.5		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
7.685	1.303E+03	1.001E+04	18.874	5.074E+02	9.577E+03			

Data Set Number = 15 Bulk Oil % = 0.0

TIME: 18:25:06

TC No:	1	2	3	4	5	6	7	8
Temp :	6.06	6.30	6.25	6.16	-99.99	6.00	5.99	6.27
TC No:	9	10	11	12	13	14	15	16
Temp :	16.55	27.13	21.72	25.96	9.99	27.21	18.11	22.75
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
6.12	21.11	2.24	2.20	2.23	-1.74	-11.6		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
3.893	1.267E+03	4.931E+03	18.889	5.062E+02	9.561E+03			

Data Set Number = 16 Bulk Oil % = 0.0

TIME: 18:25:41

TC No:	1	2	3	4	5	6	7	8
Temp :	6.02	6.37	6.33	6.22	-99.99	5.98	5.99	6.32
TC No:	9	10	11	12	13	14	15	16
Temp :	16.58	27.16	21.75	25.99	10.01	27.24	18.15	22.77
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
6.15	21.14	2.28	2.23	2.27	-1.69	-11.6		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
3.881	1.271E+03	4.933E+03	18.876	5.069E+02	9.567E+03			

Data Set Number = 17 Bulk Oil % = 0.0

TIME: 18:30:07

TC No:	1	2	3	4	5	6	7	8
Temp :	4.46	4.65	4.63	4.56	-99.99	4.42	4.43	4.64
TC No:	9	10	11	12	13	14	15	16
Temp :	16.75	27.50	22.00	26.31	10.14	27.59	18.34	23.05
Twa	ATwa	Tliqd	Tliqd2	Tvapr	Psat	Tsump		
4.63	21.39	2.30	2.24	2.27	-1.69	-11.7		
Thetab	Htube	Qdp	Athetab	Ahtube	AuQdp			
2.255	1.258E+03	2.359E+03	19.121	5.090E+02	9.732E+03			

Data Set Number = 18 Bulk Oil % = 0.0

TIME: 18:30:52
 TC No: 1 2 3 4 5 6 7 8
 Temp : 4.49 4.65 4.64 4.58 -99.99 4.44 4.44 4.64
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.75 27.48 21.98 26.30 10.11 27.57 18.33 23.05
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 4.54 21.38 2.30 2.24 2.28 -1.68 -11.7
 Thetab Htube Qdp Athetab Ahtube AuQdp
 2.262 1.259E+03 2.847E+03 19.104 5.067E+02 9.681E+03

Data Set Number = 19 Bulk Oil % = 0.0

TIME: 18:35:00
 TC No: 1 2 3 4 5 6 7 8
 Temp : 3.39 3.46 3.46 3.42 -99.99 3.33 3.34 3.46
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.68 27.38 21.91 26.19 10.12 27.45 18.27 22.93
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 3.40 21.30 2.25 2.20 2.22 -1.74 -11.8
 Thetab Htube Qdp Athetab Ahtube AuQdp
 1.176 1.306E+03 1.536E+03 19.079 5.060E+02 9.654E+03

Data Set Number = 20 Bulk Oil % = 0.0

TIME: 18:35:42
 TC No: 1 2 3 4 5 6 7 8
 Temp : 3.42 3.48 3.49 3.46 -99.99 3.37 3.38 3.50
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.70 27.38 21.91 26.19 10.09 27.46 18.27 22.95
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 3.43 21.30 2.30 2.23 2.27 -1.69 -11.8
 Thetab Htube Qdp Athetab Ahtube AuQdp
 1.165 1.319E+03 1.537E+03 19.034 5.083E+02 9.676E+03

Data Set Number = 21 Bulk Oil % = 0.0

TIME: 18:40:25
 TC No: 1 2 3 4 5 6 7 8
 Temp : 2.68 2.68 2.69 2.67 -99.99 2.64 2.65 2.71
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.66 27.28 21.83 26.10 10.16 27.37 18.22 22.88
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 2.67 21.25 2.23 2.21 2.23 -1.73 -11.9
 Thetab Htube Qdp Athetab Ahtube AuQdp
 .444 1.404E+03 6.232E+02 19.020 5.044E+02 9.593E+03

Data Set Number = 22 Bulk Oil % = 0.0

TIME: 18:41:07
 TC No: 1 2 3 4 5 6 7 8
 Temp : 2.71 2.71 2.73 2.70 -99.99 2.67 2.67 2.73
 TC No: 9 10 11 12 13 14 15 16
 Temp : 16.67 27.30 21.84 26.11 10.07 27.38 18.22 22.90
 Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsump
 2.70 21.25 2.29 2.22 2.26 -1.70 -11.9
 Thetab Htube Qdp Athetab Ahtube AuQdp
 .439 1.415E+03 6.216E+02 18.985 5.031E+02 9.551E+03

NOTE: 22 data runs were stored in file DAT0406042

APPENDIX D. PROGRAM SETUP72

Program SETUP72 is listed on the following pages. The program enables the user to:

1. Monitor coolant sump temperature.
2. Monitor liquid pool average temperature.
3. Monitor all thermocouple channel output temperatures.
4. Monitor voltage, current, and resulting power supplied to the upper tube heater (main heater) as well as the resistance of the heater.
5. Monitor the voltage, current, and resulting power supplied to the lower tube heater (auxiliary heater) as well as the resistance of the heater.

Program SETUP72 is written in Hewlett-Packard Basic 5.0 for the HP 9300 series computer.

```

1  PROGRAM: SETUP
2  DATE: AUGUST 3, 1991
4  PROGRAMMER: LT DEAN SUGIYAMA
5  MODIFIED BY LANNIE LAKE JAN 22, 1992
10 COM /C6/ C(7)
20 DATA 0.10095091,25727.94369,-767345.9295,79025595.91,-9247486589,6.97699E+
11,-2.56192E+13
21 DATA 3.94079E+14
22 READ C(4)
23 ON KEY 1,15 GOTO 27
25 PRINTER IS !
27 PRINT
29 PRINT
30 PRINT USING "4X,""SELECT OPTION""
31 PRINT USING "6X,""0-MONITOR SUMP""
32 PRINT USING "6X,""1-MONITOR LIQUID""
33 PRINT USING "6X,""2-CHECK THERMOCOUPLES""
34 PRINT USING "6X,""3-CHECK MAIN HEATER""
35 PRINT USING "6X,""4-CHECK AUX HEATERS""
36 PRINT USING "6X,""5-EXIT PROGRAM""
37 PRINT USING "4X,""NOTE: KEY 1 = ESCAPE""
39 BEEP
40 INPUT Ido
41 IF Ido=5 THEN Ido=5
42 IF Ido=0 THEN 50
43 IF Ido=1 THEN 155
44 IF Ido=2 THEN 173
45 IF Ido=3 THEN 195
46 IF Ido=4 THEN 195
47 IF Ido=5 THEN 231
49 PRINT
491
50 PRINT
51 PRINT "SUMP TEMPERATURE DEG C "
53 PRINT
54 OUTPUT 709;"AR AF19 AL19 URS"
59 OUTPUT 709;"AS SA"
70 Sum=0
90 FOR J=1 TO 5
90 ENTER 709:E
100 Sum=Sum+E
110 NEXT J
120 Eave=Sum/5
130 Temp=FNTvsv(Eave)
140 PRINT USING "4X,M00.00":Temp
141 BEEP
142 PRINT
150 WAIT 5
151 GOTO 50
1521
155 PRINT
156 PRINT "LIQUID TEMPERATURE DEG C"
159 PRINT
159 OUTPUT 709;"AR AF16 AL17 URS"
160 Sum=0
161 FOR I=1 TO 2
162 OUTPUT 709;"AS SA"
163 ENTER 709:E
164 Sum=Sum+E

```

```

165 NEXT I
166 Eave=Sum/2
167 Temp=FNTvav(Eave)
168 PRINT USING "4X,MOD.00":Temp
169 GEEP
170 WAIT S
171 GOTO 155
172
173 PRINT
174 PRINT "CHANNEL      TEMPERATURE DEG C"
175 OUTPUT 709:"AR AF00 AL19 URS"
176 FOR I=1 TO 20
177 OUTPUT 709:"AS SA"
178 Sum=0
179 FOR J=1 TO 5
180 ENTER 709:E
181 Sum=Sum+E
182 NEXT J
183 Eave=Sum/5
184 Temp=FNTvav(Eave)
185 PRINT TAB(3):I:TAB(15):Temp
186 NEXT I
187 GEEP
188 WAIT S
189 GOTO 173
190
191 PRINT
192 OUTPUT 709:"AR AF20 AL22 URS"
193 FOR I=1 TO 3
194 OUTPUT 709:"AS SA"
195 Sum=0
196 FOR J=1 TO 5
197 ENTER 709:E
198 Sum=Sum+E
199 NEXT J
200 IF I=1 THEN Volt=Sum/5
201 IF I=2 AND Ido=3 THEN
202 PRINT "MAKE SURE VOLTAGE BOX IS SET TO MAIN HEATERS"
203 Amp=Sum/5
204 END IF
205 IF I=3 AND Ido=4 THEN
206 PRINT "MAKE SURE VOLTAGE BOX IS SET TO AUX HEATERS"
207 Amp=Sum/5
208 END IF
209 NEXT I
210 Amp=ABS(Amp*1.9182)
211 Volt=ABS(Volt*25)
212 Power=Volt*Amp
213 Resistance=Volt/Amp
214 PRINT
215 GEEP
216 PRINT "VOLTAGE(V) CURRENT(A) RESISTANCE(ohms) POWER(W)"
217 PRINT
218 PRINT USING "1X,5M0000.00,4X":Volt,Amp,Resistance,Power
219 WAIT S
220 GOTO 195
221 GEEP
222 PRINT
223 PRINT "THAT'S ALL FOLKS!"
224 END

```

```

235 DEF FNTABV(U)
236 COM /C6/ C(7)
237 T=C(0)
238 FOR I=1 TO 7
239 T=T+C(I)*U*I
240 NEXT I
241 T=T+9.626897E-2+T*(3.761199E-3-T*5.0589259E-5)
242 RETURN T
250 FEND

```

APPENDIX E. PROGRAM DRP72

The data acquisition and reduction program DRP72 is listed on the following pages. Program DRP72 is written in Hewlett-Packard Basic 5.0 for the HP 9300 series computer.

```

10  FILE NAME: ORPT2
20  DATE:      MARCH 9, 1992
30  REVISED VERSION OF ORPT1 FOR TWO TUBE DATA
40  REVISED BY Lannie Lake
50  COM /Ido/ Ido
60  PRINTER IS !
70  CALL Select
80  INPUT "WANT TO SELECT ANOTHER OPTION (1=Y,0=N)?",Isel
90  IF Isel=1 THEN GOTO 70
100 BEEP
110 BEEP
120 PRINTER IS !
130 PRINT "DATA COLLECTION/REPROCESSING COMPLETED"
140 END
150 SUB Main
160 COM /Ido/ Ido
170 COM /Co/ C(7),Ical
180 COM /W1/ O2,O1,Do,L,Lu,Kcu
190 DIM Emf(20),I(20),O1s(13),O2s(13),O1a(13),O2a(13),La(13),Lu(13),Kcua(13),
200 DATA 0.10096091,25727.94369,-767345.8295,79025595.91
210 DATA -9247486589,5.97699E+11,-2.56192E+13,3.94079E+14
220 READ C(*)
230 DATA "Smooth","High Flux","Thermoexel-E","Thermoexel-HE"
240 DATA Smooth,High Flux,Turbo-B,High Flux Mod,Turbo-B Mod
250 READ Ins(*)
260 PRINTER IS 70!
270 BEEP
280 IF Ido=4 THEN PRINTER IS !
290 IF Ido=4 THEN GOTO 3030
300 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Dates$
310 OUTPUT 709:"TD":Dates$
320 OUTPUT 709:"TD"
330 ENTER 709:Dates$
340 PRINT
350 PRINT "      Month, Date and Time :":Dates$
360 PRINT "      Date : ",DATE$(TIMEDATE)
370 PRINT
380 PRINT USING "10X","NOTE: Program name : ORPT2"
390 BEEP
400 INPUT "ENTER DISK NUMBER",On
410 PRINT USING "15X","Disk number = ",22":On
420 BEEP
430 INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
440 BEEP
450 INPUT "1 OR 2 TUBE OPERATION (ENTER 1 OR 2)",Humntu
460 BEEP
470 INPUT "SELECT HEATING MODE (0=ELEC: 1=WATER)",Ihm
480 BEEP
490 INPUT "ENTER THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
500 IF Im=0 THEN
510 BEEP
520 INPUT "GIVE A NAME FOR THE RAW DATA FILE",O2_files
530 PRINT USING "15X","New file name: ",14A":O2_files
540 Size1=20
550 CREATE 90AT O2_files,Size1
560 ASSIGN OF:file2 TO O2_files
570
580 DUMMY FILE UNTIL Name KNOWN

```



```

530 01_files="DUMMY"
540 CREATE 9DAT 01_files,Size1
510 ASSIGN 9File1 TO 01_files
520 OUTPUT 9File1:Dates
530 IF Ihm=0 THEN
540 BEEP
550 INPUT "ENTER NUMBER OF DEFECTIVE TCS (0=DEFAULT)",Idtc
560 IF Idtc=0 THEN
570 Ldtc1=0
580 Ldtc2=0
590 PRINT USING "16X","No defective TCs exist""
600 END IF
610 IF Idtc=1 THEN
620 BEEP
630 INPUT "ENTER DEFECTIVE TC LOCATION (1-9)",Ldtc1
640 PRINT USING "16X","TC is defective at location "",00":Ldtc1
650 Ldtc2=0
660 END IF
670 IF Idtc=2 THEN
680 BEEP
690 INPUT "ENTER DEFECTIVE TC LOCATIONS (1-9)",Ldtc1,Ldtc2
700 PRINT USING "16X","TC are defective at locations "",00,4X,00":Ldtc1,Ldtc2
710 END IF
720 IF Idtc>2 THEN
730 BEEP
740 PRINTER IS 1
750 BEEP
760 PRINT "INVALID ENTRY"
770 PRINTER IS 701
780 GOTO 640
790 END IF
800 END IF
810 OUTPUT 9File1:Ldtc1,Ldtc2
820 IF Hmntu=1 THEN GOTO 1190
830 INPUT "ENTER NUMBER OF DEFECTIVE AUX TCS (0=DEFAULT)",Aldtc
840 IF Aldtc=0 THEN
850 Aldtc1=0
860 Aldtc2=0
870 PRINT USING "16X","No defective AUX TCs exist""
880 END IF
890 IF Aldtc=1 THEN
900 BEEP
910 INPUT "ENTER DEFECTIVE TC LOCATION (9-16)",Aldtc1
920 PRINT USING "16X","TC is defective at location "",00":Aldtc1
930 Aldtc2=0
940 END IF
950 IF Aldtc=2 THEN
960 BEEP
970 INPUT "ENTER DEFECTIVE TC LOCATIONS (9-16)",Aldtc1,Aldtc2
980 PRINT USING "16X","TC are defective at locations "",00,4X,00":Aldtc1,Aldtc2
990 END IF
1000 IF Aldtc>2 THEN
1010 BEEP
1020 PRINTER IS 1
1030 BEEP
1040 PRINT "INVALID ENTRY"
1050 PRINTER IS 701
1060 GOTO 640
1070 END IF

```

```

1130 OUTPUT @File1:Aldtc1,Aldtc2
1190' Im=1 option
1200 ELSE
1210 BEEP
1220 INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D2_files
1230 PRINT USING "16X","Old file name: ",14A":D2_files
1240 ASSIGN @File2 TO D2_files
1250 ENTER @File2:Nrun
1260 ENTER @File2:Gold$
1270 PRINT USING "16X","This data set taken on : ",14A":Gold$
1290 ENTER @File2:Ldte1,Ldte2,Aldtc1,Aldtc2
1290 IF Ldte1>0 OR Ldte2>0 THEN
1300 PRINT USING "16X","Thermocouples were defective at locations:",2(30,4X)":
Ldte1,Ldte2
1310 END IF
1320 IF Humntu=1 THEN GOTO 1350
1330 IF Aldtc1>0 OR Aldtc2>0 THEN
1340 PRINT USING "16X","AUX Thermocouples were defective at locations:",2(30,4
X)":Aldtc1,Aldtc2
1350 END IF
1360 ENTER @File2:Itt
1370 END IF
1390 Idtc=0
1390 IF Ldte1>0 THEN Idtc=Idtc+1
1400 IF Ldte2>0 THEN Idtc=Idtc+1
1410 IF Humntu=1 THEN GOTO 1440
1420 IF Aldtc1>0 THEN Aldtc=Aldtc+1
1430 IF Aldtc2>0 THEN Aldtc=Aldtc+1
1440' IF Im=0 AND Ihm=1 THEN 1595
1450 BEEP
1460 INPUT "WANT TO CREATE A PLOT FILE? (0=N,1=Y)",Iplot
1470 IF Iplot=1 THEN
1490 BEEP
1490 INPUT "GIVE NAME FOR PLOT FILE",P_files
1500 CREATE BDAT P_files,4
1510 ASSIGN @Plot TO P_files
1520 END IF
1530 IF Ihm=1 THEN
1540 BEEP
1550 INPUT "WANT TO CREATE Uo FILE? (0=N,1=Y)",Iuf
1560 IF Iuf=1 THEN
1570 BEEP
1580 INPUT "ENTER Uo FILE NAME",Ufiles
1590 CREATE BDAT Ufiles,4
1600 ASSIGN @Ufile TO Ufiles
1610 END IF
1620 BEEP
1630 INPUT "WANT TO CREATE Re FILE? (0=N,1=Y)",Ire
1640 IF Ire=1 THEN
1650 BEEP
1660 INPUT "ENTER Re FILE NAME",Refiles
1670 CREATE BDAT Refiles,10
1680 ASSIGN @Refile TO Refiles
1690 END IF
1700 END IF
1710 PRINTER IS 1
1720 IF Im=0 THEN
1730 BEEP
1740 PRINT USING "16X","Select tube number:"
1750 IF Ihm=0 THEN

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1760 PRINT USING "SX,""0 Smooth 4 inch Ref""
1770 PRINT USING "SX,""1 Smooth 4 inch Cu (Press/Slide)""
1780 PRINT USING "SX,""2 Soft Solder 4 inch Cu""
1790 PRINT USING "SX,""3 Soft Solder 4 inch HIGH FLUX""
1800 PRINT USING "SX,""4 Wieland Hard 9 inch""
1810 PRINT USING "SX,""5 HIGH FLUX 9 inch""
1820 PRINT USING "SX,""6 GEWA-K 40 Fins/in""
1830 PRINT USING "SX,""7 GEWA-K 25 Fins/in""
1840 PRINT USING "SX,""9 GEWA-T 19 Fins/in""
1850 PRINT USING "SX,""9 GEWA-T OR GEWA-TY 25 Fins/in""
1860 PRINT USING "SX,""10 THERMOEXCEL-E""
1870 PRINT USING "SX,""11 THERMOEXCEL-ME""
1880 PRINT USING "SX,""12 TURBO-B""
1890 PRINT USING "SX,""13 GEWA-K 19 Fins/in""
1900 ELSE
1910 PRINT USING "SX,""0 Smooth tube""
1920 PRINT USING "SX,""1 High Flux""
1930 PRINT USING "SX,""2 Turbo-B""
1940 PRINT USING "SX,""3 High Flux Mod""
1950 PRINT USING "SX,""4 Turbo-B Mod""
1960 END IF
1970 INPUT Itt
1980 OUTPUT #File1:Itt
1990 END IF
2000 PRINTER IS 701
2010 IF Itt<10 THEN PRINT USING "16X,""Tube Number: """,0":Itt
2020 IF Itt>9 THEN PRINT USING "16X,""Tube Number: """,00":Itt
2030 IF Ihm=1 THEN PRINT USING "16X,""Tube Type: """,15A":Tns(Itt)
2040 BEEP
2050 INPUT "ENTER OUTPUT VERSION (0=LONG,1=SHORT,2=NONE)",Iav
2060 BEEP
2070 INPUT "SELECT (0=LIQ,1=VAP,2=(LIQ+VAP)/2)",Ilav
2080
2090
2090 DIMENSIONS FO TESTED TUBES
2100 ELECTRIC HEATED MODE
2110 D1=Diameter at thermocouple positions
2120 DATA .0111125,.0111125,.0111125,.0129540,.012446,.0129540,.0100965
2130 DATA .0100965,.01157,.01157,.01157,.01157,.01157,.0100965
2140 READ Dia(*)
2150 D1=D1a(Itt)
2160
2170 D2=Diameter of test section to the base of fins
2180 DATA .015975,.015975,.015975,.015924,.015975,.015924,.01270
2190 DATA .0127,.0139,.0139,.0139,.0139,.0139,.0127
2200 READ D2a(*)
2210
2220 D1=Inside diameter of unenhanced ends
2230 DATA .0127,.0127,.0127,.0132,.0127,.0132,.0111125,.0111125
2240 DATA .0119,.0119,.0119,.0119,.0119,.0111125
2250 READ Dia(*)
2260
2270 D2=Outside diameter of unenhanced ends
2280 DATA .015975,.015975,.015975,.015924,.015975,.015924,.01270,.01270
2290 DATA .01331,.01331,.01331,.01331,.0159,.0127
2300 READ D2a(*)
2310
2320 L=Length of enhanced surface
2330 DATA .016,.016,.016,.016,.0032,.0032,.0032,.0032,.0032,.0032,.0032,.0032
2340 READ La(*)

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23501
23601 Lu=Length of unenhanced surface at the ends
2370 DATA .0254,.0254,.0254,.0254,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.07
62,.0762,.0762
2380 READ Lus(*)
23901
24001 Kcu=Thermal Conductivity of tube
2410 DATA 399,344,344,45,344,45,344,344,399,399,399,399,344
2420 READ Kcu(*)
2430 IF Ihm=1 THEN
24401
24501 Data statements for water heating mode
24601
2470 DATA 0.015875,0.015875,0.0169,0.0139,0.0169,0,0,0,0,0
2480 READ O2a(*)
2490 DATA 0.0127,0.0127,0.0145,0.0127,0.0145,0,0,0,0,0
2500 READ O1a(*)
2510 DATA 0.015875,0.015875,0.0169,0.015875,0.0169,0,0,0,0,0
2520 READ O0a(*)
2530 DATA 0.3048,0.3048,0.3048,0.3048,0.3048,0,0,0,0,0
2540 READ La(*)
2550 DATA 0.0254,0.0254,0.0254,0.0254,0.0254,0,0,0,0,0
2560 READ Lus(*)
2570 DATA 398,45,398,45,398,0,0,0,0,0
2580 READ Kcu(*)
2590 END IF
2600 O2=O2a(Itt)
2610 O1=O1a(Itt)
2620 O0=O0a(Itt)
2630 L=La(Itt)
2640 Lu=Lus(Itt)
2650 Kcu=Kcu(Itt)
2660 Xn=.8
2670 Fr=.3
2680 IF Itt=0 THEN Cf=1.70E+9
2690 IF Itt>0 THEN Cf=3.7037E+10
2700 A=PI*(O0^2-O1^2)/4
2710 P=PI*O0
2720 IF Ihm=1 THEN
2730 BEEP
2740 INPUT "TUBE INITIATION MODE. (1=HOT WATER,2=STEAM,3=COLD WATER)",Itim
2750 IF Itim=1 THEN PRINT USING "16X,""Tube Initiate: Hot Water""
2760 IF Itim=2 THEN PRINT USING "16X,""Tube Initiate: Steam""
2770 IF Itim=3 THEN PRINT USING "16X,""Tube Initiate: Cold Water""
2780 INPUT "TEMP/VEL MODE: (0=T-CONST,U-DEC;1=T-DEC,U-CONST; 2=T-INC,U-CONST)",
Itv
2790 IF Itv=0 THEN PRINT USING "16X,""Temp/Vel Mode: Constant/Decreasing""
2800 IF Itv=1 THEN PRINT USING "16X,""Temp/Vel Mode: Decreasing/Constant""
2810 IF Itv=2 THEN PRINT USING "16X,""Temp/Vel Mode: Increasing/Constant""
2820 INPUT "WANT TO RUN WILSON PLOT? (1=Y,0=N)",Iw1
2830 IF Ihm=1 AND Iw1=0 THEN
2840 IF Itt=0 THEN C1=.032
2850 IF Itt=1 OR Itt=3 THEN C1=.059
2860 IF Itt=2 OR Itt=4 THEN C1=.062
2870 BEEP
2880 INPUT "ENTER C1 (DEF: WH=.032,HF=.059,TS=.062)",C1
2890 PRINT USING "16X,""Sieder-Tate ""
2900 PRINT USING "16X,"" Constant = "",2.40";C1
2910 END IF
2920 END IF

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2930 IF Ihm=1 AND Im=1 AND Iwt=1 THEN
2940 IF Itt=0 THEN C1=.032
2950 IF Itt=1 OR Itt=3 THEN C1=.053
2960 IF Itt=2 OR Itt=4 THEN C1=.062
2970 ASSIGN %File2 TO *
2980 CALL Wilson(C1,C1)
2990 ASSIGN %File2 TO %File3
3000 ENTER %File2:Nrun,Dold$,Ldtd1,Ldtd2,Itt
3010 END IF
3020 Nsub=0
3030 IF Ido=4 THEN Ihm=1
3040 IF Ihm=1 THEN Nsub=9
3050 Ntc=6
3060 IF Ihm=0 THEN Ntc=20
3070 J=1
3080 Sx=0
3090 Sy=0
3100 Sxs=0
3110 Sxy=0
3120 Repeat: 1
3130 IF Im=0 THEN
3140 Dold=2.22
3150 Ido=2
3160 ON KEY 1,15 RECOVER 3120
3170 PRINTER IS 1
3180 PRINT USING "4X,""SELECT OPTION""
3190 PRINT USING "6X,""0-TAKE DATA""
3200 IF Ihm=0 THEN PRINT USING "6X,""1-SET HEAT FLUX""
3210 IF Ihm=1 THEN PRINT USING "6X,""1-SET WATER FLOW RATE""
3220 PRINT USING "6X,""2-SET Tsat""
3230 PRINT USING "6X,""3-SET AUX HEAT FLUX""
3240 PRINT USING "4X,""NOTE: KEY 1 = ESCAPE""
3250 BEEP
3260 INPUT Ido
3270 IF Ido>3 THEN Ido=3
3280 IF Ido=0 THEN 5290
3290
3300 LOOP TO SET HEAT FLUX OR FLOWMETER SETTING
3310 IF Ido=1 THEN
3320 IF Ihm=0 THEN
3330 OUTPUT 709:"AR AF20 AL21 VRS"
3340 BEEP
3350 INPUT "ENTER DESIRED Qdp",Qdpd
3360 PRINT USING "4X,""DESIRED Qdp ACTUAL Qdp""
3370 Err=1000
3380 FOR I=1 TO 3
3390 OUTPUT 709:"AS SA"
3400 Sum=0
3410 FOR J=1 TO 5
3420 ENTER 709:E
3430 Sum=Sum+E
3440 NEXT J
3450 IF I=1 THEN Volt=Sum/5
3460 IF I=2 THEN Amp=Sum/5
3470 NEXT I
3480 Amp=ABS(Amp+1.3132)
3490 Volt=ABS(Volt+.25)
3500 Qdpd=Volt*Amp/PI*.02*L
3510 IF ABS(Qdpd-Qdpd)/Err THEN
3520 IF Qdpd.Qdpd THEN

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3530 BEEP 4000,.2
3540 BEEP 4000,.2
3550 BEEP 4000,.2
3560 ELSE
3570 BEEP 250,.2
3580 BEEP 250,.2
3590 BEEP 250,.2
3600 END IF
3610 PRINT USING "4X,MZ.3DE,2X,MZ.3DE":Dadd,Aadd
3620 WAIT 2
3630 GOTO 3390
3640 ELSE
3650 BEEP
3660 PRINT USING "4X,MZ.3DE,2X,MZ.3DE":Dadd,Aadd
3670 Err=500
3680 WAIT 2
3690 GOTO 3390
3700 END IF
3710 ELSE
3720 BEEP
3730 INPUT "ENTER FLOWMETER SETTING",Fms
3740 GOTO 3190
3750 END IF
3760 END IF
3770
3780 LOOP TO SET Tsat
3790 IF Ido=2 THEN
3800 IF Ikdt=1 THEN 3850
3810 BEEP
3820 INPUT "ENTER DESIRED Tsat",Dtld
3830 PRINT USING "4X," DTsat ATsat Rate Tv Rate""
3840 Ikdt=1
3850 Old1=0
3860 Old2=0
3870 Nn=1
3880 Nrs=Nn MOD 15
3890 Nn=Nn+1
3900 IF Nrs=1 THEN
3910 IF Ihm=0 THEN PRINT USING "4X," Tsat Tld1 Tld2 Tv Tsump
...
3920 IF Ihm=1 THEN PRINT USING "4X," Tsat Tld1 Tld2 Tv Tsump Tlnle
t Taile Tout""
3930 END IF
3940 IF Ihm=0 THEN OUTPUT 709:"AR AF16 AL19 VRS"
3950 IF Ihm=1 THEN OUTPUT 709:"AR AF0 ALS VRS"
3960 FOR I=1 TO 5
3970 IF Ihm=0 AND I>4 THEN 4240
3980 Sum=0
3990 OUTPUT 709:"AS SA"
4000 FOR J1=1 TO 20
4010 ENTER 709:El1q
4020 Sum=Sum+El1q
4030 NEXT J1
4040 El1q=Sum/20
4050 Tld=ENTVsv(El1q)
4060 IF I=1 THEN Tld1=Tld
4070 IF I=2 THEN Tld2=Tld
4080 IF I=3 THEN T=Tld
4090 IF I=4 THEN Tsump=Tld
4100 IF I=5 THEN Tlnlet=Tld

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4110 IF I=5 THEN Tout=Tld
4120 NEXT I
4130 IF Ihm=1 THEN
4140 OUTPUT 709:"AR AF00 AL00 URS"
4150 OUTPUT 709:"AS SA"
4160 Sum=0
4170 FOR Kk=1 TO 20
4180 ENTER 709:E
4190 Sum=Sum+E
4200 NEXT Kk
4210 Enf(7)=ABS(Sum/20)
4220 Tpils=Enf(7)/3.96E-4
4230 END IF
4240 Atld=(Tld1+Tld2)*.5
4250 IF ABS(Atld-Otld)>.2 THEN
4260 IF Atld>Otld THEN
4270 BEEP 4000,.2
4280 BEEP 4000,.2
4290 BEEP 4000,.2
4300 ELSE
4310 BEEP 250,.2
4320 BEEP 250,.2
4330 BEEP 250,.2
4340 END IF
4350 Err1=Atld-Old1
4360 Old1=Atld
4370 Err2=Tw-Old2
4380 Old2=Tw
4390 IF Tld1>100. THEN 4440
4400 IF Ihm=0 THEN PRINT USING "4X,5(M000.00,2X)":Otld,Tld1,Tld2,Tv,Tsump
4410 IF Ihm=1 AND Idp=0 THEN PRINT USING "4X,7(M00.00,2X)":Otld,Tld1,Tld2,Tv,Ts
ump,Tinlet,Tpils
4420 IF Ihm=1 AND Idp=4 THEN PRINT USING "4X,5(M00.00,2X),3(M30.00,2X)":Otld,Tl
d1,Tld2,Tv,Tsump,Tinlet,Tpils,Tout
4430 WAIT 2
4440 GOTO 3990
4450 ELSE
4460 IF ABS(Atld-Otld)>.1 THEN
4470 IF Atld>Otld THEN
4480 BEEP 3000,.2
4490 BEEP 3000,.2
4500 ELSE
4510 BEEP 900,.2
4520 BEEP 900,.2
4530 END IF
4540 Err1=Atld-Old1
4550 Old1=Atld
4560 Err2=Tw-Old2
4570 Old2=Tw
4580 IF Ihm=0 THEN PRINT USING "4X,5(M000.00,2X)":Otld,Tld1,Tld2,Tv,Tsump
4590 IF Ihm=1 THEN PRINT USING "4X,5(M00.00,2X),3(M30.00,1X)":Otld,Tld1,Tld2,Tv
,Tsump,Tinlet,Tpils,Tout
4600 WAIT 2
4610 GOTO 3990
4620 ELSE
4630 BEEP
4640 Err1=Atld-Old1
4650 Old1=Atld
4660 Err2=Tw-Old2
4670 Old2=Tw

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4630 IF Ihm=0 THEN PRINT USING "4X,5(M000.00,2X)":Ot1d,T1d1,T1d2,Tv,Tsump
4630 IF Ihm=1 THEN PRINT USING "4X,9(M000.00,2X)":Ot1d,T1d1,T1d2,Tv,Tsump,Tinlet
,Tp1e,Tout
4700 WAIT 2
4710 GOTO 3990
4720 END IF
4730 END IF
4740 END IF
4750 '
4750' LOOP TO SET AUX HEAT FLUX
4770 IF Ida=3 THEN
4780 IF Ihm=0 THEN
4790 PRINT " SET VOLT BOX TO AUX"
4900 OUTPUT 709:"AR AF20 AL22 VRS"
4910 BEEP
4920 INPUT "ENTER DESIRED AuxQdp",Duxqdp
4930 PRINT USING "2X,""DESIRED AuxQdp ACTUAL AuxQdp""
4940 Err=1000
4950 FOR I=1 TO 3
4960 OUTPUT 709:"AS SA"
4970 Sum=0
4980 FOR J1=1 TO 5
4990 ENTER 709:E
4990 Sum=Sum+E
4910 NEXT J1
4920 IF I=1 THEN Volt=Sum/5
4930 IF I=3 THEN Amp=Sum/5
4940 NEXT I
4950 Amp=ABS(Amp*1.9192)
4960 Volt=ABS(Volt*25)
4970 Auxqdp=Volt*Amp/(PI*02*L)
4980 IF ABS(Auxqdp-Duxqdp)>Err THEN
4990 IF Auxqdp>Duxqdp THEN
5000 BEEP 4000,.2
5010 BEEP 4000,.2
5020 BEEP 4000,.2
5030 ELSE
5040 BEEP 250,.2
5050 BEEP 250,.2
5060 BEEP 250,.2
5070 END IF
5080 PRINT USING "4X,MZ.3DE,2X,MZ.3DE":Duxqdp,Auxqdp
5090 WAIT 2
5100 GOTO 4850
5110 ELSE
5120 BEEP
5130 PRINT USING "4X,MZ.3DE,2X,MZ.3DE":Duxqdp,Auxqdp
5140 Err=500
5150 WAIT 2
5160 GOTO 4850
5170 END IF
5180 GOTO 3190
5190 END IF
5200 END IF
5210' ERROR TRAP FOR Ida OUT OF BOUNDS
5220 IF Ida>3 THEN
5230 BEEP
5240 GOTO 3190
5250 END IF
5250'

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5270 TAKE DATA IF Im=0 LOOP
5280 IF Ikol=1 THEN G320
5290 BEEP
5300 INPUT "ENTER BULK OIL %",Sep
5310 Ikol=1
5320 IF Ihm=0 THEN OUTPUT 709;"AR AF00 AL19 VRS"
5330 IF Ihm=1 THEN OUTPUT 709;"AR AF0 ALS VRS"
5340 IF Ihm=0 THEN Ntc=20
5350 FOR I=1 TO Ntc
5360 OUTPUT 709;"AS SA"
5370 Sum=0
5380 FOR Ji=1 TO 20
5390 ENTER 709:E
5400 Sum=Sum+E
5410 IF I=(17-Nsub) OR I=(19-Nsub) THEN Et(Ji-1)=E
5420 NEXT Ji
5430 Kdl=0
5440 IF I=(17-Nsub) OR I=(18-Nsub) THEN
5450 Eave=Sum/20
5460 Sum=0.
5470 FOR Jk=0 TO 19
5480 IF ABS(Et(Jk)-Eave)<5.0E-6 THEN
5490 Sum=Sum+Et(Jk)
5500 ELSE
5510 Kdl=Kdl+1
5520 END IF
5530 NEXT Jk
5540 IF I=(17-Nsub) OR I=(19-Nsub) THEN PRINT USING "4X,""Kdl = "",00":Kdl
5550 IF Kdl>10 THEN
5560 BEEP
5570 BEEP
5580 PRINT USING "4X,""Too much scattering in data - repeat data set""
5590 GOTO 3170
5600 END IF
5610 END IF
5620 Enf(I)=Sum/(20-Kdl)
5630 NEXT I
5640 IF Ihm=1 THEN
5650 OUTPUT 709;"AR AF00 AL00 VRS"
5660 OUTPUT 709;"AS SA"
5670 Sum=0
5680 FOR Kk=1 TO 20
5690 ENTER 709:E
5700 Sum=Sum+E
5710 NEXT Kk
5720 Enf(7)=ABS(Sum)/20
5730 END IF
5740 IF Ihm=0 THEN
5750 Coun=0.
5750 OUTPUT 709;"AR AF20 AL22 VRS"
5770 FOR I=1 TO 3
5780 OUTPUT 709;"AS SA"
5790 Sum=0
5800 FOR Ji=1 TO 5
5810 ENTER 709:E
5820 Sum=Sum+E
5830 NEXT Ji
5840 IF Coun=0. THEN
5850 IF I=1 THEN Un=Sum/5
5860 IF I=2 THEN In=Sum/5

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5870 ELSE
5880 IF I=1 THEN Avn=Sum/S
5890 IF I=3 THEN Air=Sum/S
5900 END IF
5910 NEXT I
5920 IF Humntu=1 THEN GOTO 5910
5930 IF Coun=0 THEN
5940 PRINT "SHIFT VOLT BOX TO AUX"
5950 END IF
5960 IF Coun=1 THEN GOTO 5900
5970 INPUT "TAKE AUX READINGS(!=YES)?",Ccon
5980 Coun=Coun+Ccon
5990 GOTO 5770
6000 END IF
6010 ELSE
6020 IF Ihm=0 THEN ENTER @File2:8op,Told$,Emf(*),Un,In,Avn,Air
6030 IF Ihm=1 THEN ENTER @File2:8op,Told$,Emf(*),Fns
6040 END IF
6050
6060 CONVERT emf'S TO TEMP,VOLT,CURRENT
6070 Twa=0
6080 Atwa=0
6090 FOR I=1 TO Ntc
6100 IF Idtc>0 THEN
6110 IF I=Ldte1 OR I=Ldte2 THEN
6120 T(I)=-99.99
6130 GOTO 6300
6140 END IF
6150 END IF
6160 IF Humntu=1 THEN GOTO 6230
6170 IF Aldtc>0 THEN
6180 IF I=Aldte1 OR I=Aldte2 THEN
6190 T(I)=-99.99
6200 GOTO 6300
6210 END IF
6220 END IF
6230 IF Itt<4 AND Ihm=0 THEN
6240 IF I>4 AND I<9 THEN
6250 T(I)=-99.99
6260 GOTO 6300
6270 END IF
6280 END IF
6290 T(I)=FNTvsv(Emf(I))
6300 NEXT I
6310 IF Itt<4 THEN
6320 FOR I=1 TO 4
6330 IF I=Ldte1 OR I=Ldte2 THEN
6340 Twa=Twa
6350 ELSE
6360 Twa=Twa+T(I)
6370 END IF
6380 NEXT I
6390 Twa=Twa/(4-Idtc)
6400 ELSE
6410 IF Ihm=1 THEN 6600
6420 FOR I=1 TO 9
6430 IF I=Ldte1 OR I=Ldte2 THEN
6440 Twa=Twa
6450 ELSE
6460 Twa=Twa+T(I)

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6470 END IF
6480 NEXT I
6490 Tw=Tw*(9-Idtc)
6500 IF Hwmntu=1 THEN GOTO 6500
6510 FOR I=9 TO 16
6520 IF I=Aldtc1 OR I=Aldtc2 THEN
6530 Atwa=Atwa
6540 ELSE
6550 Atwa=Atwa+T(I)
6560 END IF
6570 NEXT I
6580 Atw=Atwa/(9-Aldtc)
6590 END IF
6600 Tld=T(17-Nsub)
6610 Tld2=T(19-Nsub)
6620 Tlda=(Tld+Tld2)*.5
6630 Tv=T(19-Nsub)
6640 IF Itt=3 AND Ihm=0 THEN
6650 Tld2=-99.99
6660 Tv=(T(10)+T(11))/2
6670 END IF
6680 Tsump=T(20-Nsub)
6690 IF Ihm=0 THEN 6720
6700 Tinlet=T(13-Nsub)
6710 Tout=T(14-Nsub)
6720 IF Ihm=0 THEN
6730 Amp=ABS(In)*1.9192)
6740 Volt=ABS(Un)*25
6750 Q=Volt*Amp
6760 IF Hwmntu=1 THEN GOTO 6900
6770 Auamp=ABS(Ain)*1.9192)
6780 Auvolt=ABS(Avn)*25
6790 Auq=Auvolt*Auamp
6800 END IF
6810 IF Itt=0 AND Ihm=0 THEN
6820 Kcu=FNKcu(Tw)
6830 ELSE
6840 Kcu=Kcu(Itt)
6850 END IF
6860
6870 FOURIER CONDUCTION EQUATION WITH CONTACT RESISTANCE NEGLECTED
6880 IF Ihm=0 THEN Tw=Tw-Q*LOG(D2/D1)/(2*PI*Kcu*L)
6890 IF Hwmntu=1 THEN GOTO 6910
6900 IF Ihm=0 THEN Atw=Atw-Auq*LOG(D2/D1)/(2*PI*Kcu*L)
6910 IF Ilqv=0 THEN Tsat=Tlda
6920 IF Ilqv=1 THEN Tsat=Tv
6930 IF Ilqv=2 THEN Tsat=(Tlda+Tv)*.5
6940 IF Ihm=1 THEN
6950 Tavg=Tinlet
6960 Grad=37.3953+.104399*Tavg
6970 Tdrop=ABS(Enf(7))*1.E-6/(10*Grad)
6980 Tavgc=Tinlet-Tdrop*.5
6990 IF ABS(Tavg-Tavgc)>.01 THEN
7000 Tavg=(Tavg+Tavgc)*.5
7010 GOTO 6960
7020 END IF
7030
7040 COMPUTE WATER PROPERTIES
7050 IF Ihm=1 THEN
7060 Fu=FNFu(Tavg)

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```

7070 Muwa=FNMuw(Tavg)
7080 Cpw=FNCPw(Tavg)
7090 Prw=FNPrw(Tavg)
7100 Rhow=FNRRhow(Tavg)
7110 Twi=Tavg
7120
7130 Compute Mdot
7140 Mdot=3.3557E-3+Fms*(3.61955E-3-Fms*(9.92006E-5-Fms*(1.23699E-7-Fms*4.31997
5-10)))
7150 Mdot=Mdot*(1.0385-Tinlet*(1.96644E-3-Tinlet*5.252E-5))/1.0037
7160 Kdt=0
7170 Q=Mdot*Cpw*Tdrop
7180 Lntd=Tdrop/LOG((Tinlet-Tsat)/(Tinlet-Tdrop-Tsat))
7190 Uo=Q/(PI*Do*L*Lntd)
7200 Rw=Do*LOG(Do/Di)/(2.*Kou)
7210 Tw=Tsat+F*Lntd
7220 Uw=Mdot/(Rhow*PI*Di**2/4)
7230 Rew=Rhow*Uw*Di/Muwa
7240 Hi=Ci*Kw/Di*Rew*.9*Prw**(1/3.)*(Muwa/FNMuw(Twi))**.14
7250 Twic=Tavg-Q/(PI*Do*L*Hi)
7260 IF ABS(Twi-Twic)>.01 THEN
7270 Twi=(Twi+Twic)*.5
7280 GOTO 7240
7290 END IF
7300 Twi=(Twi+Twic)*.5
7310 Ho=1/(1/Uo-Do/(Di*Hi)-Rw)
7320 END IF
7330 END IF
7340 IF Ihw=1 THEN
7350 Thetab=Q/(Ho*PI*Do*L)
7360 Tw=Tsat+Thetab
7370 ELSE
7380 Thetab=Tw-Tsat
7390 IF Hwnntu=1 THEN GOTO 7400
7390 Athetab=Atw-Tsat
7400 END IF
7410 IF Thetab<0 THEN
7420 BEEP
7430 INPUT "TWALLTSAT (0=CONTINUE, 1=END)",Iev
7440 IF Iev=0 THEN GOTO 3130
7450 IF Iev=1 THEN 9930
7460 END IF
7470 IF Hwnntu=1 THEN GOTO 7540
7490 IF Athetab<0 THEN
7490 BEEP
7500 INPUT "AUX TWALLTSAT (0=CONTINUE, 1=END)",Alev
7510 IF Alev=0 THEN GOTO 3130
7520 IF Alev=1 THEN 9930
7530 END IF
7540
7550 COMPUTE VARIOUS PROPERTIES
7560 Tfilm=(Tw+Tsat)*.5
7570 Rho=FNRRho(Tfilm)
7580 Mu=FNMu(Tfilm)
7590 Kw=FNK(Tfilm)
7600 Cp=FNCP(Tfilm)
7610 Beta=FNBBeta(Tfilm)
7620 Hfg=FNHfg(Tsat)
7630 Hi=Mu*Rho
7640 Alpha=Kw/Rho*Cp

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```

7650 Pr=Ni.Alpha
7660 Psat=FNPsat(Tsat)
7670
7680 COMPUTE VARIOUS PROPERTIES FOR AUX TUBE
7690 IF Humntu=1 THEN GOTO 7790
7700 Atfilm=(Atw+Tsat)*.5
7710 Arho=FNrho(Atfilm)
7720 Amu=FNmu(Atfilm)
7730 Ak=FNk(Atfilm)
7740 Acp=FNcp(Atfilm)
7750 Abeta=FNbeta(Atfilm)
7760 Ani=Amu/Arho
7770 Aalpha=Ak/(Arho*Acp)
7780 Apr=Ani/Aalpha
7790
7800 COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
7810 FOR UNENHANCED END(S)
7820 Hbar=190
7830 Fe=(Hbar*P/(Kcu*A))**.5*Lu
7840 Tanh=FNtanh(Fe)
7850 Theta=Thetab*Tanh/Fe
7860 Xx=(9.91*Beta*Thetab*Do**3*Tanh/(Fe*Ni.Alpha))**.166667
7870 Yy=(1+(.559/Pr)**(9/16))**.25
7880 Hbarc=K/Do*(.5+.397*Xx/Yy)**2
7890 IF ABS((Hbar-Hbarc)/Hbarc)>.001 THEN
7900 Hbar=(Hbar+Hbarc)*.5
7910 GOTO 7830
7920 END IF
7930
7940 COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
7950 FOR UNENHANCED END(S) FOR AUX TUBE
7960 IF Humntu=1 THEN GOTO 8090
7970 Ahbar=190
7980 Fe=(Ahbar*P/(Kcu*A))**.5*Lu
7990 Atanh=FNtanh(Fe)
8000 Atheta=Athetab*Atanh/Fe
8010 Axx=(9.91*Beta*Thetab*Do**3*Atanh/(Fe*Ani.Aalpha))**.166667
8020 Ayy=(1+(.559/Pr)**(9/16))**.25
8030 Ahbarc=Ak/Do*(.5+.397*Axx/Ayy)**2
8040 IF ABS((Ahbar-Ahbarc)/Ahbarc)>.001 THEN
8050 Ahbar=(Ahbar+Ahbarc)*.5
8060 GOTO 7980
8070 END IF
8080
8090 COMPUTE HEAT LOSS RATE TH "HIGH UNENHANCED END(S)
8100 Q1=(Hbar*P*Kcu*A)**.5*Theta*Tanh
8110 Qc=Q-2*Q1
8120 As=P*.02*L
8130
8140 COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S) OF AUX TUBE
8150 IF Humntu=1 THEN GOTO 8190
8160 Aq1=(Ahbar*P*Kcu*A)**.5*Atheta*Atanh
8170 Aqc=Aq-2*Aq1
8180
8190 COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT
8200 Qdp=Qc/As
8210 Htube=Qdp/Thetab
8220 Gsf=(Qc*Thetab/Hfg)*(Qdp/(Mu*Hfg**.311*(3.21*Prho**.5*(1+.7*Pr**.7))
8230
8240 COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT FOR AUX TUBE

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9350 IF Hwmntu=1 THEN GOTO 9390
9350 Auqdp=Aqp/As
9370 Ahtube=Auqdp/Athetab
9390 Acsf=(Acp*Athetab/Hfg)/(Auqdp/(Amu*Hfg)+(.014/(9.91*Arho))**.5)**(1/3.)*Apr**1
.7)
9390
9390 RECORD TIME OF DATA TAKING
9390 IF Im=0 THEN
9390 OUTPUT 709:"TO"
9390 ENTER 709:Tolds
9390 END IF
9390
9390 OUTPUT DATA TO PRINTER
9390 PRINTER IS 701
9390 IF Iov=0 THEN
9390 PRINT
9400 PRINT USING "10X,""Data Set Number = "",000,2X,""Bulk Oil % = "",00.0,5X,1
4A";J,Bop,Tolds
9410 PRINT USING "10X,""Data Set Number = "",000,2X,""Bulk Oil % = "",00.0";J,B
op
9420 PRINT " TIME:",TIME$(TIMEDATE)
9430 IF Ihm=0 THEN
9440 PRINT USING "10X,""TC No: 1 2 3 4 5 6 7
9""
9450 PRINT USING "10X,""Temp :",9(1X,MOD.00);T(1),T(2),T(3),T(4),T(5),T(6),T(
7),T(8)
9450 IF Hwmntu=1 THEN GOTO 9490
9460 PRINT USING "10X,""TC No: 9 10 11 12 13 14 15
15""
9470 PRINT USING "10X,""Temp :",8(1X,MOD.00);T(9),T(10),T(11),T(12),T(13),T(1
4),T(15),T(16)
9480 PRINT USING "10X,"" Twa ATwa Tliqd Tliqd2 Tvapr Psat Tsumo""
9490 PRINT USING "10X,3(MOD.00,1X),1X,MOD.00,1X,2(1X,MOD.00),2X,MOD.0";Tw,Atw,T
ld,Tld2,Tv,Psat,Tsumo
9500 PRINT USING "10X,"" Thetab Htube Qdp Athetab Ahtube AuQd
p""
9510 PRINT USING "10X,MOD.30,1X,MZ.30E,1X,MZ.30E,1X,MOD.30,1X,MZ.30E,1X,MZ.30E"
;Thetab,Htube,Qdp,Athetab,Ahtube,Auqdp
9520 ELSE
9530 PRINT USING "10X,"" Fms Vw Tsat Tlnl Tdroop Thetab q Uo
Ho""
9540 PRINT USING "10X,4(20.00,1X),2.30,1X,00.00,1X,3(MZ.30E,1X);Fms,Vw,Tsat,Tl
nlet,Tdroop,Thetab,Qdp,Uo,Ho
9550 END IF
9550 END IF
9570 IF Iov=1 THEN
9580 IF J=1 THEN
9590 PRINT
9600 IF Ihm=0 THEN
9610 PRINT USING "10X,"" RUN No Oil% Tsat Htube Qdp Thetab""
9620 ELSE
9630 PRINT USING "10X,"" FMS OIL% TSAT HTUBE QDP THETAB""
9640 END IF
9650 END IF
9660 IF Ihm=0 THEN
9670 PRINT USING "10X,30,1X,00,2X,MOD.00,3(1X,MZ.30E);J,Bop,Tsat,Htube,Qdp,The
tab
9680 ELSE
9690 PRINT USING "10X,30,1X,00,2X,MOD.00,3(1X,MZ.30E);Fms,Bop,Tsat,Htube,Qdp,T
hetab

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```

9700 END IF
9710 END IF
9720 IF Im=0 THEN
9730 BEEP
9740 INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?" ,Ok
9750 END IF
9760 IF Ok=1 OR Im=1 THEN J=J+1
9770 IF Ok=1 AND Im=0 THEN
9780 IF Ihm=0 THEN OUTPUT @File1:8op,Told$,Emf(+),Ur,Ir,Avr,Air
9790 IF Ihm=1 THEN OUTPUT @File1:8op,Told$,Emf(+),Fms
9800 END IF
9810 IF Iuf=1 THEN OUTPUT @Ufile:Uw,Uo
9820 IF Irs=1 THEN OUTPUT @Rfile:Fms,Rew
9830 IF (Im=1 OR Ok=1) AND Iplot=1 THEN OUTPUT @Plot:Qdp,Thetab
9840 IF Im=0 THEN
9850 BEEP
9860 INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?" ,Go_on
9870 Nrun=J
9880 IF Go_on=0 THEN 9930
9890 IF Go_on<>0 THEN Repeat
9900 ELSE
9910 IF J<Nrun+1 THEN Repeat
9920 END IF
9930 IF Im=0 THEN
9940 BEEP
9950 PRINT USING "10X,"NOTE: ",J," data runs were stored in file ",I0A";J-
1,02_files
9960 ASSIGN @File1 TO *
9970 OUTPUT @File2:Nrun-1
9980 ASSIGN @File1 TO O1_files
9990 ENTER @File1:Dates,Ldtc1,Ldtc2,Itt
9991 IF Humntu=1 THEN GOTO 9000
9993 ENTER @File1:Aldtc1,Aldtc2
9000 OUTPUT @File2:Dates,Ldtc1,Ldtc2,Itt
9001 IF Humntu=1 THEN GOTO 9010
9003 OUTPUT @File2:Aldtc1,Aldtc2
9010 FOR I=1 TO Nrun-1
9020 IF Ihm=0 THEN
9030 ENTER @File1:8op,Told$,Emf(+),Ur,Ir
9040 IF Humntu=1 THEN GOTO 9060
9050 ENTER @File1:Avr,Air
9060 OUTPUT @File2:8op,Told$,Emf(+),Ur,Ir
9070 IF Humntu=1 THEN GOTO 9090
9080 OUTPUT @File2:Avr,Air
9090 ELSE
9100 ENTER @File1:8op,Told$,Emf(+),Fms
9110 OUTPUT @File2:8op,Told$,Emf(+),Fms
9120 END IF
9130 NEXT I
9140 ASSIGN @File1 TO *
9150 PURSE "DUMMY"
9160 END IF
9170 BEEP
9180 PRINT
9190 IF Iplot=1 THEN PRINT USING "10X,"NOTE: ",J," X-Y pairs were stored in
plot data file ",I0A";J-1,0_files
9200 ASSIGN @File3 TO *
9210 ASSIGN @Plot TO *
9220 IF Iuf=1 THEN ASSIGN @Ufile TO *
9230 IF Irs=1 THEN ASSIGN @Rfile TO *

```

```

9210 CALL Stats
9250 GEEP
9260 INPUT "LIKE TO PLOT DATA (I=Y,0=N)?",OK
9270 IF OK=1 THEN CALL Plot
9290 SUBEND
9300
9300 CURVE FITS OF PROPERTY FUNCTIONS
9310 DEF FNKcu(T)
9320 OFHC COPPER 250 TO 300 K
9330 Tk=T+273.15 'C TO K
9340 K=434-.112*T
9350 RETURN K
9360 FNEND
9370 DEF FNMu(T)
9380 170 TO 360 K CURVE FIT OF VISCOSITY
9390 Tk=T+273.15 'C TO K
9400 Mu=EXP(-4.4636+(1011.47/Tk))*1.0E-3
9410 RETURN Mu
9420 FNEND
9430 DEF FNCp(T)
9440 180 TO 400 K CURVE FIT OF Cp
9450 Tk=T+273.15 'C TO K
9460 Cp=.40198+1.65007E-3*Tk+1.51494E-5*Tk^2-6.67953E-10*Tk^3
9470 Cp=Cp*1000
9480 RETURN Cp
9490 FNEND
9500 DEF FNRho(T)
9510 Tk=T+273.15 'C TO K
9520 X=1-(1.9*Tk/753.95) 'K TO R
9530 Ro=35.32+51.146414*X^(1/3)+16.419015*X+17.476838*X^1.5+1.119829*X^2
9540 Ro=Ro/.962429
9550 RETURN Ro
9560 FNEND
9570 DEF FNPp(T)
9580 Pr=FNCp(T)*FNMu(T)/FNK(T)
9590 RETURN Pr
9600 FNEND
9610 DEF FNK(T)
9620 T:350 K WITH T IN C
9630 K=.071-.000251*T
9640 RETURN K
9650 FNEND
9660 DEF FNTanh(X)
9670 P=EXP(X)
9680 Q=1/P
9690 Tanh=(P-Q)/(P+Q)
9700 RETURN Tanh
9710 FNEND
9720 DEF FNTsev(U)
9730 COM /Cp/ C(T),Ical
9740 T=C(0)
9750 FOR I=1 TO 7
9760 T=T+C(I)*U^I
9770 NEXT I
9780 IF Ical=1 THEN
9790 T=T-6.7422934E-2*T*(9.0277043E-3-T*(-9.3259917E-5))
9800 ELSE
9810 T=T+9.6259917E-2*T*(3.751399E-3-T*5.3699259E-5)
9820 END IF
9830 RETURN T

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9940 FNEND
9950 DEF FNSeta(T)
9960 Rop=FNRho(T+.1)
9970 Rom=FNRho(T-.1)
9980 Beta=-2/(Rop+Rom)*(Rop-Rom)/.2
9990 RETURN Beta
9990 FNEND
9910 DEF FNHfg(T)
9920 Hfg=1.3741344E+5-T*(3.3094361E+2+T*.2165143)
9930 RETURN Hfg
9940 FNEND
9950 DEF FNPsat(Tc)
9960 0 TO 90 deg F CURVE FIT OF Psat
9970 Tf=1.8*Tc+32
9980 Pa=5.945525+Tf*(.15352092+Tf*(1.4940963E-3+Tf*9.6150671E-6))
9990 Pg=Pa-14.7
10000 IF Pg>0 THEN      I +=PSIG,--in Hg
10010 Psat=Pg
10020 ELSE
10030 Psat=Pg*29.92/14.7
10040 END IF
10050 RETURN Psat
10050 FNEND
10070 DEF FNHsmooth(X,Bop,Isat)
10080 DIM A(5),B(5),C(5),D(5)
10090 DATA .20525,.25322,.319048,.55322,.79909,1.00258
10100 DATA .74515,.72992,.73189,.71225,.68472,.64197
10110 DATA .41092,.17726,.25142,.54806,.81916,1.0845
10120 DATA .74403,.72913,.72565,.696691,.665867,.61889
10130 READ A(*),B(*),C(*),D(*)
10140 IF Bop<6 THEN I=Bop
10150 IF Bop=6 THEN I=4
10160 IF Bop=10 THEN I=5
10170 IF Isat=1 THEN
10180 Hs=EXP(A(I)+B(I)*LOG(X))
10190 ELSE
10200 Hs=EXP(C(I)+D(I)*LOG(X))
10210 END IF
10220 RETURN Hs
10230 FNEND
10240 DEF FNPoly(X)
10250 COM /Cpoly/ A(10),C(10),B(5),Nop,Iprnt,Opp,Ilog,Ifn,Ijoin,Njoin
10260 X1=X
10270 Poly=B(0)
10280 FOR I=1 TO Nop
10290 IF Ilog=1 THEN X1=LOG(X)
10300 Poly=Poly+B(I)*X1^I
10310 NEXT I
10320 IF Ilog=1 THEN Poly=EXP(Poly)
10330 RETURN Poly
10340 FNEND
10350 SUB Poly
10360 DIM R(10),S(10),Sy(10),Sx(10),Xx(100),Yy(100)
10370 COM /Cpoly/ A(10),C(10),B(5),N,Iprnt,Opp,Ilog,Ifn,Ijoin,Njoin
10380 COM /Xxyy/ Xp(25),Yp(25)
10390 FOR I=0 TO 4
10400 B(I)=0
10410 NEXT I
10420 BEEP
10430 INPUT "SELECT (0=FILE,1=KEYBOARD,2=PROGRAM)",In

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10440 Im=Im+1
10450 BEEP
10460 INPUT "ENTER NUMBER OF X-Y PAIRS",Np
10470 IF Im=1 THEN
10480 BEEP
10490 INPUT "ENTER DATA FILE NAME",D_files
10500 BEEP
10510 INPUT "LIKE TO EXCLUDE DATA PAIRS (1=Y,0=N)?",Ied
10520 IF Ied=1 THEN
10530 BEEP
10540 INPUT "ENTER NUMBER OF PAIRS TO BE EXCLUDED",Ipex
10550 END IF
10560 ASSIGN @File TO D_files
10570 ELSE
10580 BEEP
10590 INPUT "WANT TO CREATE A DATA FILE (1=Y,0=N)?",Yes
10600 IF Yes=1 THEN
10610 BEEP
10620 INPUT "GIVE A NAME FOR DATA FILE",D_files
10630 CREATE BOAT D_files,5
10640 ASSIGN @File TO D_files
10650 END IF
10660 END IF
10670 BEEP
10680 INPUT "ENTER THE ORDER OF POLYNOMIAL",N
10690 FOR I=0 TO N+2
10700 Sy(I)=0
10710 Sx(I)=0
10720 NEXT I
10730 IF Ied=1 AND Im=1 THEN
10740 FOR I=1 TO Ipex
10750 ENTER @File:X,Y
10760 NEXT I
10770 END IF
10780 FOR I=1 TO Np
10790 IF Im=1 THEN
10800 IF Opo=2 THEN ENTER @File:X,Y
10810 IF Opo<2 THEN ENTER @File:Y,X
10820 IF Opo=1 THEN Y=Y/X
10830 IF Ilog=1 THEN
10840 IF Opo=2 THEN Xt=X/Y
10850 X=LOG(X)
10860 IF Opo=2 THEN Y=LOG(Xt)
10870 IF Opo<2 THEN Y=LOG(Y)
10880 END IF
10890 END IF
10900 IF Im=2 THEN
10910 BEEP
10920 INPUT "ENTER NEXT X-Y PAIR",X,Y
10930 IF Yes=1 THEN OUTPUT @File:X,Y
10940 END IF
10950 IF Im=3 THEN
10960 Xx(I)=X
10970 Yy(I)=Y
10980 ELSE
10990 X=Xp(I-1)
11000 Y=Yp(I-1)
11010 END IF
11020 P=Q=Y
11030 Sy/Q=Sy/Q+Y

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```

11040 S(I)=X
11050 Sx(I)=Sx(I)+X
11060 FOR J=1 TO N
11070 R(J)=R(J)+X
11080 Sy(J)=Sy(J)+R(J)
11090 NEXT J
11100 FOR J=2 TO N+2
11110 S(J)=S(J-1)+X
11120 Sx(J)=Sx(J)+S(J)
11130 NEXT J
11140 NEXT I
11150 IF Yes=1 AND Im=2 THEN
11160 BEEP
11170 PRINT USING "12X,00," "X-Y pairs were stored in file ",10A":No,O_files
11180 END IF
11190 Sx(0)=No
11200 FOR I=0 TO N
11210 C(I)=Sy(I)
11220 FOR J=0 TO N
11230 A(I,J)=Sx(I+J)
11240 NEXT J
11250 NEXT I
11260 FOR I=0 TO N-1
11270 CALL Divide(I)
11280 CALL Subtract(I+1)
11290 NEXT I
11300 B(N)=C(N)/A(N,N)
11310 FOR I=0 TO N-1
11320 B(N-1-I)=C(N-1-I)
11330 FOR J=0 TO I
11340 B(N-1-I)=B(N-1-I)-A(N-1-I,N-J)*B(N-J)
11350 NEXT J
11360 B(N-1-I)=B(N-1-I)/A(N-1-I,N-1-I)
11370 NEXT I
11380 PRINTER IS 701
11390 PRINT B(*)
11400 PRINTER IS 705
11410 IF Iprnt=0 THEN
11420 PRINT USING "12X," "EXPONENT    COEFFICIENT"
11430 FOR I=0 TO N
11440 PRINT USING "15X,00,5X,MO.70E":I,B(I)
11450 NEXT I
11460 PRINT " "
11470 PRINT USING "12X," "DATA POINT      X          Y          Y(CALCULATED) DISCR
EPANCY"
11480 FOR I=1 TO No
11490 Yc=B(0)
11500 FOR J=1 TO N
11510 Yc=Yc+B(J)*Xx(I)*J
11520 NEXT J
11530 O=Yy(I)-Yc
11540 PRINT USING "15X,30,4X,4(MO.5DE,1X)":I,Xx(I),Yy(I),Yc,O
11550 NEXT I
11560 END IF
11570 ASSIGN %File TO *
11580 SUBEND
11590 SUB Divide(M)
11600 COM Call: A(0,0)=C(0)/B(0),N,Iprnt,Dec,Ilog,Ifo,Ijoin,Njoin
11610 FOR I=M TO N
11620 A(I,M)=A(I,M)

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```

11630 FOR J=M TO N
11640 A(I,J)=A(I,J)/Ac
11650 NEXT J
11660 C(I)=C(I)/Ac
11670 NEXT I
11690 SUBEND
11690 SUB Subtract(K)
11700 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
11710 FOR I=K TO N
11720 FOR J=K-1 TO N
11730 A(I,J)=A(K-1,J)-A(I,J)
11740 NEXT J
11750 C(I)=C(K-1)-C(I)
11760 NEXT I
11770 SUBEND
11790 SUB Plin
11790 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
11900 COM /Xxyy/ Xx(25),Yy(25)
11810 PRINTER IS 705
11820 BEEP
11830 INPUT "WANT TO PLOT Uo vs Uw? (1=Y,0=N)",Iuo
11840 IF Iuo=0 THEN
11850 BEEP
11860 INPUT "SELECT (0=h/h0% same tube,1=h(HF)/h(sm)",Irt
11870 BEEP
11880 INPUT "SELECT h/h RATIO (1=FILE,0=COMPUTED)",Ihrt
11890 IF Ihrt=0 THEN
11900 BEEP
11910 INPUT "WHICH Tsat (1=6.7,0=-2.2)",Isat
11920 END IF
11930 Xmin=0
11940 Xmax=10
11950 Xstep=2
11960 IF Irt=0 THEN
11970 Ymin=0
11980 Ymax=1.4
11990 Ystep=.2
12000 ELSE
12010 Ymin=0
12020 Ymax=15
12030 Ystep=5
12040 END IF
12050 ELSE
12060 Opo=2
12070 Ymin=0
12080 Ymax=12
12090 Ystep=3
12100 Xmin=0
12110 Xmax=4
12120 Xstep=1
12130 END IF
12140 IF Ihrt=1 THEN
12150 Ymin=0
12160 Ymax=18
12170 Ystep=3
12180 Xmin=0
12190 Xmax=9
12200 Xstep=2
12210 END IF
12220 BEEP

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12220 PRINT "IN:SP:IP 0000,0200,3300,5300:"
12240 PRINT "SC 0,100,0,100:TL 2,0:"
12260 Sfx=100/(Xmax-Xmin)
12280 Sfy=100/(Ymax-Ymin)
12300 PRINT "PU 0,0 PD"
12320 FOR Xa=Xmin TO Xmax STEP Xstep
12340 X=(Xa-Xmin)*Sfx
12360 PRINT "PA:X,";0:XT:"
12380 NEXT Xa
12400 PRINT "PA 100,0:PU:"
12420 PRINT "PU PA 0,0 PD"
12440 FOR Ya=Ymin TO Ymax STEP Ystep
12460 Y=(Ya-Ymin)*Sfy
12480 PRINT "PA 0,";Y,"YT"
12500 NEXT Ya
12520 PRINT "PA 0,100 TL 0 2"
12540 FOR Xa=Xmin TO Xmax STEP Xstep
12560 X=(Xa-Xmin)*Sfx
12580 PRINT "PA:X,";100:XT"
12600 NEXT Xa
12620 PRINT "PA 100,100 PU PA 100,0 PD"
12640 FOR Ya=Ymin TO Ymax STEP Ystep
12660 Y=(Ya-Ymin)*Sfy
12680 PRINT "PD PA 100,";Y,"YT"
12700 NEXT Ya
12720 PRINT "PA 100,100 PU"
12740 PRINT "PA 0,-2 SR 1.5,2"
12760 FOR Xa=Xmin TO Xmax STEP Xstep
12780 X=(Xa-Xmin)*Sfx
12800 PRINT "PA:X,";0:"
12820 IF Iuo=0 THEN PRINT "CP -2,-1:LB":Xa:""
12840 IF Iuo=1 THEN PRINT "CP -1.5,-1:LB":Xa:""
12860 NEXT Xa
12880 PRINT "PU PA 0,0"
12900 FOR Ya=Ymin TO Ymax STEP Ystep
12920 IF ABS(Ya)<1.E-5 THEN Ya=0
12940 Y=(Ya-Ymin)*Sfy
12960 PRINT "PA 0,";Y,""
12980 IF Iuo=0 THEN PRINT "CP -4,-.35:LB":Ya:""
13000 IF Iuo=1 THEN PRINT "CP -3,-.35:LB":Ya:""
13020 NEXT Ya
13040 Xlabels="Oil Percent"
13060 IF Iuo=0 THEN
13080 IF Int=0 THEN
13100 Ylabels="h/h0%"
13120 ELSE
13140 Ylabels="h/hsmooth"
13160 END IF
13180 PRINT "SR 1.5,2:PU PA 50,-10 CP:;-LEN(Xlabels)/2:0:LB":Xlabels:""
13200 PRINT "PA -11,50 CP 0,";:-LEN(Ylabels)/2*5/6:0I 0,1:LB":Ylabels:""
13220 PRINT "CP 0,0"
13240 ELSE
13260 PRINT "SP0:SP2"
13280 PRINT "SR 1.2,2.4:PU PA -9.35:OI 0,1:LBUIPR 1,0.5:LB9o:PR -1,0.5:LB (kW/m
13300 PRINT "PR -1,0.5:SP 1,1.5:LB2:SR 1.5,2:PR .5,.5:LB:PR .5,0:LBK)"
13320 PRINT "PA 40,-10:OI 1,0:LBUIPR 1,1,-1:LBw:PR 1,.5:LB(4.5)"
13340 PRINT "SP0:SP1"
13360 END IF
13380 Iuo=0

```

```

12920 BEEP
12930 INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",O1p
12940 Icn=0
12950 IF O1p=1 THEN
12960 BEEP
12970 INPUT "ENTER THE NAME OF THE DATA FILE",D_files
12980 IF Iuc=0 THEN
12990 BEEP
13000 INPUT "SELECT (0=LINEAR, 1=LOG(X,Y))",Ilog
13010 END IF
13020 ASSIGN @File TO D_files
13030 BEEP
13040 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
13050 BEEP
13060 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
13070 IF Iuc=0 AND Ihrst=0 THEN
13080 BEEP
13090 INPUT "ENTER DESIRED HEAT FLUX",Q
13100 END IF
13110 BEEP
13120 PRINTER IS 1
13130 PRINT USING "4X,""Select a symbol: ""
13140 PRINT USING "4X,""1 Star 2 Plus sign""
13150 PRINT USING "4X,""3 Circle 4 Square""
13160 PRINT USING "4X,""5 Rombus""
13170 PRINT USING "4X,""6 Right-side-up triangle""
13180 PRINT USING "4X,""7 Up-side-down triangle""
13190 INPUT Sym
13200 PRINTER IS 705
13210 PRINT "PU DI"
13220 IF Sym=1 THEN PRINT "SM+"
13230 IF Sym=2 THEN PRINT "SM+"
13240 IF Sym=3 THEN PRINT "SMo"
13250 Nn=4
13260 IF Ilog=1 THEN Nn=1
13270 IF Md>1 THEN
13280 FOR I=1 TO (Md-1)
13290 ENTER @File:Ya,Ya
13300 NEXT I
13310 END IF
13320 IF Ihrst=0 THEN
13330 Q1=Q
13340 IF Ilog=1 THEN Q=LOG(Q)
13350 END IF
13360 FOR I=1 TO Npairs
13370 IF Iuc=0 AND Ihrst=0 THEN
13380 ENTER @File:Ya,B(*)
13390 Ya=B(I)
13400 FOR K=1 TO Nn
13410 Ya=Ya+B(K)*Q^K
13420 NEXT K
13430 END IF
13440 IF Iuc=1 OR Ihrst=1 THEN
13450 ENTER @File:Ya,Ya
13460 IF Iuc=1 THEN Ya=Ya*1000
13470 END IF
13480 IF Iuc=0 AND Ihrst=0 THEN
13490 IF Ilog=1 THEN Ya=EXP(Ya)
13500 IF Ilog=0 THEN Ya=Q1*Ya
13510 IF Int=0 THEN

```

```

13120 IF Xa=0 THEN
13130 Yc=Ya
13140 Ya=1
13150 ELSE
13160 Ya=Ya/Yc
13170 END IF
13180 ELSE
13190 Hsm=FNHsmooth(Q,Xa,Isat)
13200 Ya=Ya/Hsm
13210 END IF
13220 END IF
13230 Xx(I-1)=Xa
13240 Yy(I-1)=Ya
13250 X=(Xa-Xmin)*Sfx
13260 Y=(Ya-Ymin)*Sfy
13270 IF Sym=3 THEN PRINT "SM"
13280 IF Sym=4 THEN PRINT "SR 1.4,2.4"
13290 PRINT "PA",X,Y,""
13300 IF Sym=3 THEN PRINT "SR 1.2,1.5"
13310 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,9,4,0,:"
13320 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,5,3,5,3,-6:"
13330 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-9,-6,0,3,9:"
13340 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,9,6,0,-3,-9:"
13350 NEXT I
13360 BEEP
13370 ASSIGN %File TO *
13380 END IF
13390 PRINT "PU SM"
13400 BEEP
13410 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Okp
13420 IF Okp=1 THEN
13430 BEEP
13440 PRINTER IS 1
13450 PRINT USING "4X,";"Select line type:"
13460 PRINT USING "5X,";"0 Solid line"
13470 PRINT USING "5X,";"1 Dashed"
13480 PRINT USING "5X,";"2,,,5 Longer line - dash"
13490 INPUT Ipn
13500 PRINTER IS 705
13510 BEEP
13520 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
13530 Iprnt=1
13540 CALL Poly
13550 IF Iud=1 THEN
13560 BEEP
13570 INPUT "DESIRE TO SET X Lower and Upper Limit (1=Y,0=N)?",Ixlim
13580 IF Ixlim=0 THEN
13590 Xll=0
13600 Xul=7
13610 END IF
13620 IF Ixlim=1 THEN
13630 BEEP
13640 INPUT "ENTER X Lower Limit",Xll
13650 BEEP
13660 INPUT "ENTER X Upper Limit",Xul
13670 END IF
13680 END IF
13690 FOR Xa=Xll TO Xul STEP Xstep/25
13700 Icn=Icn+1
13710 Ya=FNPPoly(Xa)

```

```

14020 IF Iuc=1 THEN Ya=Ya 1000
14030 Y=(Ya-Ymin)*Sf/
14040 X=(Xe-Xmin)*Sf/
14050 IF Y=0 THEN Y=0
14060 IF Y 100 THEN GOTO 14150
14070 Pu=0
14080 IF Ipn=1 THEN Idf=Icn MOD 2
14090 IF Ipn=2 THEN Idf=Icn MOD 4
14100 IF Ipn=3 THEN Idf=Icn MOD 8
14110 IF Ipn=4 THEN Idf=Icn MOD 16
14120 IF Ipn=5 THEN Idf=Icn MOD 32
14130 IF Idf=1 THEN Pu=1
14140 IF Pu=0 THEN PRINT "PA",X,Y,"PD"
14150 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
14160 NEXT Xa
14170 PRINT "PU"
14180 GOTO 12920
14190 END IF
14200 BEEP
14210 INPUT "WANT TO QUIT (I=Y,0=N)?",Iquit
14220 IF Iquit=1 THEN 14240
14230 GOTO 12820
14240 PRINT "PU SP0"
14250 SUBEND
14260 SUB Stats
14270 PRINTER IS 701
14280 J=0
14290 K=0
14300 BEEP
14310 IF Iplot=1 THEN ASSIGN @File TO P_files
14320 BEEP
14330 INPUT "LAST RUN No?(0=QUIT)",Nn
14340 IF Nn=0 THEN 14700
14350 Nn=Nn-J
14360 Sx=0
14370 Sy=0
14380 Sz=0
14390 Sxs=0
14400 Sys=0
14410 Szs=0
14420 FOR I=1 TO Nn
14430 J=J+1
14440 ENTER @File:Q,T
14450 H=Q/T
14460 Sx=Sx+Q
14470 Sxs=Sxs+Q^2
14480 Sy=Sy+T
14490 Sys=Sys+T^2
14500 Sz=Sz+H
14510 Szs=Szs+H^2
14520 NEXT I
14530 Qave=Sx/Nn
14540 Tave=Sy/Nn
14550 Have=Sz/Nn
14560 Sdevq=SQR(ABS((Nn*Sxs-Sx^2)/(Nn*(Nn-1))))
14570 Sdevt=SQR(ABS((Nn*Sys-Sy^2)/(Nn*(Nn-1))))
14580 Sdevh=SQR(ABS((Nn*Szs-Sz^2)/(Nn*(Nn-1))))
14590 Sh=100*Sdevh/Have
14600 Sq=100*Sdevq/Qave
14610 St=100*Sdevt/Tave

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14620 IF K=1 THEN 14680
14630 PRINT
14640 PRINT USING "11X,";"DATA FILE:";14A:Files
14650 PRINT
14660 PRINT USING "11X,";"RUN Htube      SdevH   Qdp      SdevQ   Thetab SdevT"
14670 K=1
14680 PRINT USING "11X,00,2(2X,0.30E,1X,30.20),2X,00.30,1X,30.20";J,Have,Sh,Qave
,Sq,Tave,St
14690 GOTO 14720
14700 ASSIGN %File: TO *
14710 PRINTER IS 1
14720 SUBEND
14730 SUB Coef
14740 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Qpc,Ilog,Ifn,Ijoin,Njoin
14750 BEEP
14760 INPUT "GIVE A NAME FOR CROSS-PLOT FILE",Cpf%
14770 CREATE %DAT Cpf%,2
14780 ASSIGN %File TO Cpf%
14790 BEEP
14800 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
14810 BEEP
14820 INPUT "ENTER OIL PERCENT (-1=STOP)",%op
14830 IF %op<0 THEN 14970
14840 CALL Poly
14850 OUTPUT %File:%op,%( )
14860 GOTO 14810
14870 ASSIGN %File TO *
14880 SUBEND
14890 SUB Wilson(Cf,Ci)
14900 COM /W11/ Q2,O1,O3,L,Lu,Kcu
14910 DIM Emf(12)
14920 WILSON PLOT SUBROUTINE DETERMINE CF AND CI
14930 BEEP
14940 INPUT "ENTER DATA FILE NAME",Files
14950 BEEP
14960 PRINTER IS 1
14970 PRINT USING "4X,";"Select option:"
14980 PRINT USING "4X,";" 0 Vary Cf and Ci"
14990 PRINT USING "4X,";" 1 Fix Cf Vary Ci"
15000 PRINT USING "4X,";" 2 Vary Cf Fix Ci"
15010 INPUT "ENTER OPTION",Icfix
15020 PRINTER IS 701
15030 IF Icfix=0 THEN 15070
15040 IF Icfix=1 THEN BEEP
15050 IF Icfix=1 THEN INPUT "ENTER Cf",Csf
15060 IF Icfix=2 THEN INPUT "ENTER Ci",Ci
15070 PRINTER IS 1
15080 INPUT "Want To Vary Coeff?(1=Y,0=N)",Icccoef
15090 IF Icccoef=1 THEN INPUT "ENTER COEFF",R
15100 PRINTER IS 701
15110 IF Icfix=0 OR Icfix=2 THEN Cfs=.004
15120 IF Icfix=1 THEN Cfs=Csf
15130 Cfs=Ci
15140 In=.3
15150 F=.2
15160 J=.0
15170 P=.3
15180 IF Icccoef=1 THEN P=P/R
15190 PRINTER IS 1

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15200 PRINT D0,D1,Kcu
15210 ASSIGN @File TO Files
15220 ENTER @File:Nrun,Date$,Ldte1,Ldte2,Itt
15230 Rw=D0*LOG(D0/D1)/(C*Kcu)
15240 Sx=0
15250 Sy=0
15260 Sxy=0
15270 Sx2=0
15280 Sy2=0
15290 FOR I=1 TO Nrun
15300 ENTER @File:Rop,Told$,Emf(*),Fms
15310! CONVERT EMF'S TO TEMPERATURE
15320 FOR J=1 TO 5
15330 T(J)=FNTvsv(Emf(J))
15340 NEXT J
15350 Tsat=(T(1)+T(2))*0.5
15360 Tavg=T(5)
15370 Grad=37.9853+.104399*Tavg
15380 Tdrop=Emf(7)*1.E+5/(10.*Grad)
15390 Tavgc=T(5)-Tdrop*.5
15400 IF ABS(Tavg-Tavgc)>.01 THEN
15410 Tavg=(Tavg+Tavgc)*.5
15420 GOTO 15370
15430 END IF
15440!
15450! Compute properties of water
15460 Kw=FNKw(Tavg)
15470 Muw=FNMuw(Tavg)
15480 Cpw=FNCPw(Tavg)
15490 Prw=FNPw(Tavg)
15500 Rhow=FNRRho(Tavg)
15510!
15520! Compute properties of Freon-114
15530 Lntd=Tdrop/LOG((T(5)-Tsat)/(T(5)-Tdrop-Tsat))
15540 IF Jj=0 THEN
15550 Tw=Tsat+Fr*Lntd
15560 Thetab=Tw-Tsat
15570 Jj=1
15580 END IF
15590 Tf=(Tw+Tsat)*.5
15600 Rho=FNRRho(Tf)
15610 Mu=FNMu(Tf)
15620 K=FNK(Tf)
15630 Cp=FNCP(Tf)
15640 Beta=FNBeta(Tf)
15650 Hfg=FNHfg(Tsat)
15660 Ni=Mu/Rho
15670 Alpha=K/(Rho*Cp)
15680 Pr=Ni/Alpha
15690!
15700! Analysis
15710! COMPUTE Mdot
15720 A=PI*(D0^2-D1^2)/4
15730 P=PI*D0
15740 Mdot=3.9657E-3+Fms*(3.51955E-3-Fms*(9.92006E-5-Fms*(1.23599E-7-Fms*4.31997E-10)))
15750 Q=Mdot*Cpw*Tdrop
15760! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
15770! FOR UNENHANCED ENDS:
15780 Hbar=190

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15790 Fe=(Hbar*P/(Kcu*A))**.5*Lu
15800 Tanh=FNtanh(Fe)
15910 Theta=Thetab*Tanh/Fe
15920 Xy=(9.81*9eta*Thetab*Do**3*Tanh/(Fe*N1*Alpha))**.166667
15930 Yy=(1+(.559/Pr)**(9/16))**(9/27)
15940 Hbarc=K/Do*(.5+.397*Xx/Yy)**2
15950 IF ABS((Hbar-Hbarc)/Hbar).001 THEN
15960 Hbar=(Hbar+Hbarc)*.5
15970 GOTO 15790
15980 END IF
15990!
15900! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED ENDS
15910 Q1=(Hbar*P*Kcu*A)**.5*Thetab*Tanh
15920 Qc=Q-2*Q1
15930 As=PI*Do*L
15940! COMPUTE ACTUAL HEAT FLUX
15950 Qdp=Qc/As
15960 IF Icfix=0 OR Icfix>1 THEN Csf=1/Cf*(1./Rr)
15970 Thetab=Csf/Cp*Hfg*(Qdp/(Mu*Hfg)*(.014/(9.81*Rho))**.5)**(1./Rr)*Pr**.7
15980 Ho=Qdp/Thetab
15990 Omega=Ho/Cf
16000 Uo=Q/(PI*Do*L*LmtD)
16010 Vw=Mdot/(Rho*PI*Di**2/4)
16020 Rew=Rho*Vw*Di/Muwa
16030 Tw1=Tw+Q*Rw/(PI*Do*L)
16040 Gama=Kw/Di*Rew**.8*Fw**(1/3.)* (Vw/FNMuw(Tw1))**.14
16050! PRINTER IS 1
16060 Yw=(1./Uo-Rw)*Omega
16070 Xw=Omega*Do/(Gama*Di)
16080 Sx=Sx+Xw
16090 Sy=Sy+Yw
16100 Sxy=Sxy+Yw*Xw
16110 Sx2=Sx2+Xw*Xw
16120 Sy2=Sy2+Yw*Yw
16130 N=7 I
16140 ASSIGN @File TO *
16150 Sx=(Sx+Sy*Nrun+Sxy)/(Sx+Sx*Nrun+Sx2)
16160 Sy=(Sy-Sx*Nrun)/Nrun
16170 IF Icfix=0 OR Icfix=3 OR Icfix=4 THEN
16180 C1c=1/M
16190 Cfc=1/C
16200 END IF
16210 IF Icfix=1 THEN
16220 C1c=1/M
16230 Cfc=Cf
16240 END IF
16250 IF Icfix=2 THEN
16260 C1c=C1
16270 Cfc=1/C
16280 END IF
16290 IF ABS((C1-C1c)/C1c).001 OR ABS((Cf-Cfc)/Cfc).001 THEN
16300 C1=(C1+C1c)*.5
16310 Cf=(Cf+Cfc)*.5
16320 PRINTER IS 1
16330 PRINT USING "CY," Csf = "",M2.30E,2X," C1 = "",M2.30E,Csf,C1
16340 PRINTER IS 701
16350 GOTO 15210
16360 END IF
16370 PRINT
16380 PRINTER IS 701

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16390 PRINT USING "3X," " OF          C1""
16400 PRINT USING "9X," "ASSUMED      "" ,MZ.3DE,3X,MZ.3DE";Cfa,C1a
16410 PRINT USING "9X," "CALCULATED   "" ,MZ.3DE,3X,MZ.3DE";Csf,C1
16420 PRINT
16430 Sum2=Sy2-2*M*Sy+2*C*Sy+M*2*Sx2+2*M*C*Sx+Nrun*C*2
16440 PRINT USING "10X," "Sum of Squares = "" ,Z.3DE";Sum2
16450 PRINT USING "10X," "Coefficient = "" ,D.000";Rr
16460 SUBEND
16470 DEF FNMuw(T)
16480 A=247.9/(T+133.15)
16490 Mu=2.4E-5*10^A
16500 RETURN Mu
16510 FNEED
16520 DEF FNCpw(T)
16530 Cpw=4.21120959-T*(2.25026E-3-T*(4.42361E-5+2.71429E-7*T))
16540 RETURN Cpw*1000
16550 FNEED
16560 DEF FNRhow(T)
16570 Ro=999.52946+T*(.01269-T*(5.492513E-3-T*(1.234147E-5)))
16580 RETURN Ro
16590 FNEED
16600 DEF FNPrw(T)
16610 Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
16620 RETURN Prw
16630 FNEED
16640 DEF FNKw(T)
16650 X=(T+273.15)/273.15
16660 Kw=-.92247+X*(2.9395-X*(1.9007-X*(.52577-.07344*X)))
16670 RETURN Kw
16680 FNEED
16690 SUB Plot
16700 COM /Cply/ A(10,10),C(10),B(5),Nap,Iapnt,Opa,Ilog,Ifn,Ijoin,Njoin
16710 DIM 9s(3)
16720 INTEGER I1
16730 PRINTER IS 1
16740 Idv=0
16750 BEEP
16760 INPUT "LIKE DEFAULT VALUES FOR PLOT (1=Y,0=N)?",Idv
16770 Opa=0
16780 BEEP
16790 PRINT USING "4X," "Select Option: ""
16800 PRINT USING "5X," "0  q versus delta-T""
16810 PRINT USING "5X," "1  h versus delta-T""
16820 PRINT USING "5X," "2  h versus q""
16830 INPUT Opa
16840 BEEP
16850 INPUT "SELECT UNITS (0=SI,1=ENGLISH)",Iun
16860 PRINTER IS 705
16870 IF Idv=1 THEN
16880 BEEP
16890 INPUT "ENTER NUMBER OF CYCLES FOR X-AXIS",Cx
16900 BEEP
16910 INPUT "ENTER NUMBER OF CYCLES FOR Y-AXIS",Cy
16920 BEEP
16930 INPUT "ENTER MIN X-VALUE (MULTIPLE OF 10)",Xmin
16940 BEEP
16950 INPUT "ENTER MIN Y-VALUE (MULTIPLE OF 10)",Ymin
16960 ELSE
16970 IF Opa=0 THEN
16980 Cy=3

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```

16990 Cx=3
17000 Xmin=.1
17010 Ymin=100
17020 END IF
17030 IF Opp=1 THEN
17040 Cy=2
17050 Cx=2
17060 Xmin=.1
17070 Ymin=100
17080 END IF
17090 IF Opp=2 THEN
17100 IF Iun=0 THEN
17110 Cy=3
17120 Cx=2
17130 Xmin=1000
17140 Ymin=100
17150 ELSE
17160 Cy=3
17170 Cx=3
17180 Xmin=100
17190 Ymin=10
17200 END IF
17210 END IF
17220 END IF
17230 BEEP
17240 PRINT "IN:SP1;IP 2300,2200,9300,5800:"
17250 PRINT "SC 0,100,0,100;TL 2,0:"
17260 Sfx=100/Cx
17270 Sfy=100/Cy
17280 BEEP
17290 INPUT "WANT TO BY-PASS CASE? (I=Y,0=N)" ,Ibyo
17300 IF Ibyo=1 THEN 19540
17310 PRINT "PU 0,0 PD"
17320 Nn=9
17330 FOR I=1 TO Cx+1
17340 Xat=Xmin+10*(I-1)
17350 IF I=Cx+1 THEN Nn=1
17360 FOR J=1 TO Nn
17370 IF J=1 THEN PRINT "TL 2 0"
17380 IF J=2 THEN PRINT "TL 1 0"
17390 Xa=Xat+J
17400 X=LST(Xa/Xmin)*Sfx
17410 PRINT "PA";X," ,0: XT:"
17420 NEXT J
17430 NEXT I
17440 PRINT "PA 100,0:PU:"
17450 PRINT "PU PA 0,0 PD"
17460 Nn=9
17470 FOR I=1 TO Cy+1
17480 Yat=Ymin+10*(I-1)
17490 IF I=Cy+1 THEN Nn=1
17500 FOR J=1 TO Nn
17510 IF J=1 THEN PRINT "TL 2 0"
17520 IF J=2 THEN PRINT "TL 1 0"
17530 Ya=Yat+J
17540 Y=LST(Ya/Ymin)*Sfy
17550 PRINT "PA 0,";Y,"YT"
17560 NEXT J
17570 NEXT I
17580 PRINT "PA 0,100 TL 0 0"

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17590 Nn=9
17600 FOR I=1 TO Cx+1
17610 Xat=Xmin*10^(I-1)
17620 IF I=Cx+1 THEN Nn=1
17630 FOR J=1 TO Nn
17640 IF J=1 THEN PRINT "TL 0 2"
17650 IF J>1 THEN PRINT "TL 0 1"
17660 Xa=Xat*J
17670 X=LGT(Xa/Xmin)*Sfx
17680 PRINT "PA":X,"",100:XT
17690 NEXT J
17700 NEXT I
17710 PRINT "PA 100,100 PU PA 100,0 PD"
17720 Nn=9
17730 FOR I=1 TO Cy+1
17740 Yat=Ymin*10^(I-1)
17750 IF I=Cy+1 THEN Nn=1
17760 FOR J=1 TO Nn
17770 IF J=1 THEN PRINT "TL 0 2"
17780 IF J>1 THEN PRINT "TL 0 1"
17790 Ya=Yat*J
17800 Y=LGT(Ya/Ymin)*Sfy
17810 PRINT "PD PA 100,"",Y,"YT"
17820 NEXT J
17830 NEXT I
17840 PRINT "PA 100,100 PU"
17850 PRINT "PA 0,-2 SR 1.5,2"
17860 Ii=LGT(Xmin)
17870 FOR I=1 TO Cx+1
17880 Xa=Xmin*10^(I-1)
17890 X=LGT(Xa/Xmin)*Sfx
17900 PRINT "PA":X,"",0:"
17910 IF Ii=0 THEN PRINT "CP -2,-2:LB10:PR -2,2:LB":Ii:"
17920 IF Ii>0 THEN PRINT "CP -2,-2:LB10:PR 0,2:LB":Ii:"
17930 Ii=Ii+1
17940 NEXT I
17950 PRINT "PU PA 0,0"
17960 Ii=LGT(Ymin)
17970 Yi=10
17980 FOR I=1 TO Cy+1
17990 Ya=Ymin*10^(I-1)
18000 Y=LGT(Ya/Ymin)*Sfy
18010 PRINT "PA 0,"",Y,""
18020 PRINT "CP -4,-.25:LB10:PR -2,2:LB":Ii:"
18030 Ii=Ii+1
18040 NEXT I
18050 BEEP
18060 INPUT "WANT USE DEFAULT LABELS (1=Y,0=N)?",Id1
18070 IF Id1=1 THEN
18080 BEEP
18090 INPUT "ENTER X-LABEL",Xlabels
18100 BEEP
18110 INPUT "ENTER Y-LABEL",Ylabels
18120 END IF
18130 IF Odd=2 THEN
18140 PRINT "SP 1,2:PU PA 40,-14:"
18150 PRINT "LB1:PR -1.5,3 PD PP 1,2,0 PU:PP .5,-4:LB10:PR .5,1:"
18160 PRINT "LB-1:PR .5,-1:LB10:PR .5,1:"
18170 IF Id=0 THEN
18180 PRINT "LB) (X)"

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18190 ELSE
18200 PRINT "LB) / F)"
18210 END IF
18220 END IF
18230 IF Opo=2 THEN
18240 IF Iun=0 THEN
18250 PRINT "SR 1.5,2:PU PA 40,-14:LBq (W/m:SR 1,1.5:PR 0.5,1:LB2:SR 1.5,2:PR
0.5,-1:LB)"
18260 ELSE
18270 PRINT "SR 1.5,2:PU PA 34,-14:LBq (8tu/hr:PR .5,.5:LB.:PR .5,-.5:"
18280 PRINT "LBft:PR .5,1:SR 1,1.5:LB2:SR 1.5,2:PR .5,-1:LB):"
18290 END IF
18300 END IF
18310 IF Opo=0 THEN
18320 IF Iun=0 THEN
18330 PRINT "SR 1.5,2:PU PA -12,40:DI 0,1:LBq (W/m:PR -1,0.5:SR 1,1.5:LB2:SR 1
.5,2:PR 1,.5:LB)"
18340 ELSE
18350 PRINT "SR 1.5,2:PU PA -12,32:DI 0,1:LBq (8tu/hr:PR -.5,.5:LB.:PR .5,.5:"
18360 PRINT "LBft:SR 1,1.5:PR -1,.5:LB2:PR 1,.5:SR 1.5,2:LB)"
18370 END IF
18380 END IF
18390 IF Opo>0 THEN
18400 IF Iun=0 THEN
18410 PRINT "SR 1.5,2:PU PA -12,38:DI 0,1:LBh (W/m:PR -1,.5:SR 1,1.5:LB2:SR 1
.5,2:PR .5,.5:"
18420 PRINT "SR 1.2,2.4:PU PA -12,37:DI 0,1:LBh:PR 1,0.5:LBot:PR -1,0.5:LB (W/m
18430 PRINT "PR -1,.5:SR 1,1.5:LB2:SR 1.5,2:PR .5,.5:LB.:PR .5,0:LBK)"
18440 ELSE
18450 PRINT "SR 1.5,2:PU PA -12,29:DI 0,1:LBh (8tu/hr:PR -.5,.5:LB.:PR .5,.5:"
18460 PRINT "LBft:PR -1,.5:SR 1,1.5:LB2:SR 1.5,2:PR .5,.5:LB.:PR .5,.5:LBf)"
18470 END IF
18480 END IF
18490 IF Idl=0 THEN
18500 PRINT "SR 1.5,2:PU PA 50,-16 CP:=-LEN(Xlabels)/2:"0:LB":Xlabels:"
18510 PRINT "PA -14,50 CP 0,":=-LEN(Ylabels)/2-S/6:"DI 0,1:LB":Ylabels:"
18520 PRINT "CP 0,0 DI"
18530 END IF
18540 Ipn=0
18550 X11=-1.E+6
18560 Xu1=-1.E+6
18570 Icn=0
18580 Ifn=0
18590 Ijoin=1
18600 BEEP
18610 INPUT "WANT TO PLOT DATA FROM A FILE (I=Y,0=N)?",OI
18620 IF OI=1 THEN
18630 BEEP
18640 INPUT "ENTER THE NAME OF THE DATA FILE",D_files
18650 ASSIGN D_file TO D_files
18660 BEEP
18670 BEEP
18680 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
18690 BEEP
18700 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
18710 BEEP
18720 INPUT "CONNECT DATA WITH LINE (I=Y,0=N)?",Idl
18730 BEEP
18740 PRINTER IS 1

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19750 PRINT USING "IX,";"Select a symbol:"
19760 PRINT USING "SX,";"1 Star      2 Plus sign"
19770 PRINT USING "SX,";"3 Circle   4 Square"
19780 PRINT USING "SX,";"5 Rhombus"
19790 PRINT USING "SX,";"6 Right-side-up triangle"
19800 PRINT USING "SX,";"7 Up-side-down triangle"
19810 INPUT Sym
19820 PRINTER IS 705
19830 PRINT "PU Q1"
19840 IF Sym=1 THEN PRINT "SM+"
19850 IF Sym=2 THEN PRINT "SM+"
19860 IF Sym=3 THEN PRINT "SMo"
19870 IF Md=1 THEN
19880 FOR I=1 TO (Md-1)
19890 ENTER @File:Ya,Xa
19900 NEXT I
19910 END IF
19920 FOR I=1 TO Npairs
19930 ENTER @File:Ya,Xa
19940 IF I=1 THEN Q1=Ya
19950 IF I=Npairs THEN Q2=Ya
19960 IF Qpo=1 THEN Ya=Ya/Xa
19970 IF Qpo=2 THEN
19980 Q=Ya
19990 Ya=Ya/Xa
20000 Xa=Q
20010 END IF
20020 IF Xa<X11 THEN X11=Xa
20030 IF Xa>Xul THEN Xul=Xa
20040 IF Iun=1 THEN
20050 IF Qpo<2 THEN Xa=Xa*.18
20060 IF Qpo<0 THEN Ya=Ya*.1751
20070 IF Qpo=0 THEN Ya=Ya*.317
20080 IF Qpo=2 THEN Xa=Xa*.317
20090 END IF
20100 X=LGT(Xa/Xmin)*Sfx
20110 Y=LGT(Ya/Ymin)*Sfy
20120 Kj=0
20130 CALL Symb(X,Y,Sym,Icl,Kj)
20140 GOTO 19270
20150 IF Sym>3 THEN PRINT "SM"
20160 IF Sym<4 THEN PRINT "SR 1.4,2.4"
20170 IF Icl=0 THEN
20180 PRINT "PA",X,Y,""
20190 ELSE
20200 PRINT "PA",X,Y,"PO"
20210 END IF
20220 IF Sym=3 THEN PRINT "SR 1.2,1.6"
20230 IF Sym=4 THEN PRINT "UC2,1.99,3,-9,-4,0,0,2,1,3:"
20240 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,5,3,5,3,-6:"
20250 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-9,-6,0,3,9:"
20260 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,9,6,0,-3,-9:"
20270 NEXT I
20280 PRINT "PU"
20290 BEEP
20300 INPUT "WANT TO LABEL? (Y=Yes,N=No),I1ab"
20310 IF I1ab=1 THEN
20320 PRINT "SP0:SP0"
20330 BEEP
20340 IF K1ab=0 THEN

```



```

19350 Ylab=5
19360 Ylab=95
19370 INPUT "ENTER INITIAL X,Y LOCATIONS",Xlab,Ylab
19380 Ytt=Xlab-5
19390 Ytt=Ylab+9
19400 PRINT "SR 1,1.5"
19410 PRINT "SM:PA",Xtt,Ytt,"L9      % Heat File"
19420 Ytt=Ytt-3
19430 PRINT "PA",Xtt,Ytt,"L9      Oil Flux Name"
19440 IF Sym=1 THEN PRINT "SM+"
19450 IF Sym=2 THEN PRINT "SM+"
19460 IF Sym=3 THEN PRINT "SMo"
19470 Xlab=1
19480 END IF
19490 Kj=1
19500 CALL Symb(Xlab,Ylab,Sym,Icl,Kj)
19510 PRINT "SR 1,1.5:SM"
19520 IF Sym=4 THEN PRINT "PR 2,0"
19530 GEEP
19540 INPUT "ENTER BOP",Bop
19550 IF Bop<10 THEN PRINT "PR 2,0:L9":Bop:""
19560 IF Bop>9 THEN PRINT "PR .5,0:L9":Bop:""
19570 Ihf=0
19580 IF Q1:Q2 THEN Ihf=1
19590 IF Ihf=0 THEN PRINT "PR 4,0:L9Inc"
19600 IF Ihf=1 THEN PRINT "PR 4,0:L9Dec"
19610 PRINT "PR 2,0:L9":O_files:""
19620 PRINT "SP0:SP1:SR 1.5,2"
19630 Ylab=Ylab-5
19640 END IF
19650 GEEP
19660 ASSIGN OFile TO *
19670 X11=X11/1.2
19680 Xul=Xul*1.2
19690 GOTO 9040
19700 END IF
19710 PRINT "PU SM"
19720 GEEP
19730 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Go_on
19740 IF Go_on=1 THEN
19750 GEEP
19760 PRINTER IS 1
19770 PRINT USING "4X,""Select line type:""
19780 PRINT USING "SX,""0      Solid line""
19790 PRINT USING "SX,""1      Dashed""
19800 PRINT USING "SX,""2      S Longer line - dash""
19810 INPUT Ipn
19820 PRINTER IS 705
19830 GEEP
19840 INPUT "SELECT (0=LIN,1=LOG(X,Y))",Ilog
19850 Ipn=1
19860 CALL Poly
19870 IF Ipn=0 THEN
19880 GEEP
19890 INPUT "ENTER NUMBER OF FILES TO JOIN?",Njoin
19900 END IF
19910 Ijoin=0
19920 IF Ipn=Njoin THEN Ijoin=1
19930 IF Ipn=0 OR Ijoin=1 THEN
19940 FOR Ij=0 TO 1

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```

19950 9s(Ij)=9s(Ij)+9s(Ij)
19960 NEXT Ij
19970 Ifn=Ifn+1
19980 END IF
19990 IF Njoin=Ifn THEN
20000 FOR Ij=0 TO 3
20010 9s(Ij)=9s(Ij)/Njoin
20020 9s(Ij)=0
20030 NEXT Ij
20040 Ifn=0
20050 ELSE
20060 GOTO 19500
20070 END IF
20080 BEEP
20090 INPUT "ENTER Y LOWER AND UPPER LIMITS",Yll,Yul
20100 FOR Xx=0 TO Cx STEP Cx/200
20110 Xa=Xmin+10*Xx
20120 IF Xa>Xll OR Xa>Xul THEN 20390
20130 Icn=Icn+1
20140 Pu=0
20150 IF Ipn=1 THEN Idf=Icn MOD 2
20160 IF Ipn=2 THEN Idf=Icn MOD 4
20170 IF Ipn=3 THEN Idf=Icn MOD 9
20180 IF Ipn=4 THEN Idf=Icn MOD 15
20190 IF Ipn=5 THEN Idf=Icn MOD 29
20200 IF Idf=1 THEN Pu=1
20210 IF Opc=0 THEN Ya=FNPPoly(Xa)
20220 IF Opc=2 AND Ilog=0 THEN Ya=Xa/FNPPoly(Xa)
20230 IF Opc=2 AND Ilog=1 THEN Ya=FNPPoly(Xa)
20240 IF Opc=1 THEN Ya=FNPPoly(Xa)
20250 IF Ya<Ymin THEN 20390
20260 IF Ya>Yll OR Ya>Yul THEN 20390
20270 IF Iun=1 THEN
20280 IF Opc=2 THEN Xa=Xa+.19
20290 IF Opc=0 THEN Ya=Ya+.1761
20300 IF Opc=0 THEN Ya=Ya+.317
20310 IF Opc=2 THEN Xa=Xa+.317
20320 END IF
20330 Y=LST(Ya/Ymin)*Sfy
20340 X=LST(Xa/Xmin)*Sfx
20350 IF Y<0 THEN Y=0
20360 IF Y>100 THEN GOTO 20390
20370 IF Pu=0 THEN PRINT "PA",X,Y,"PO"
20380 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
20390 NEXT Xx
20400 PRINT "PU"
20410 GOTO 19500
20420 END IF
20430 BEEP
20440 INPUT "WANT TO PLOT REILLY'S DATA? (1=Y,0=N)",Icily
20450 IF Opc=0 OR Opc=1 THEN
20460 Xll=3
20470 Xul=20
20480 END IF
20490 IF Opc=2 THEN
20500 Yll=10000
20510 Yul=100000
20520 END IF
20530 IF I=1,=1 THEN
20540 Yll=20

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20550 Yul=70
20560 BEEP
20570 INPUT "ENTER LOWER AND UPPER Y-LIMITS FOR PLOTTING",Yll,Yul
20580 FOR Xx=0 TO Cx STEP Cx/200
20590 Xa=Xmin+10*Xx
20600 IF Xa>Xll OR Xa>Yul THEN 20730
20610 Xl=LOG(Xa)
20620 IF Opo=0 THEN Yl=-2.5402937E-1+Xl*(4.9720151-Xl+2.5134797E-1)
20630 IF Opo=1 THEN Yl=-2.5402937E-1+Xl*(3.9720151-Xl+2.5134797E-1)
20640 IF Opo=2 THEN Yl=-3.7072901E-1+Xl*(3.7259190E-1-Xl+6.9925942E-3)
20650 Ya=EXP(Yl)
20660 Y=LGT(Ya/Ymin)*Sfy
20670 X=LGT(Xa/Xmin)*Sfx
20680 Ipu=0
20690 IF Y>Yll THEN Ipu=1
20700 IF Y>Yul THEN GOTO 20730
20710 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
20720 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
20730 NEXT Xx
20740 PRINT "PU"
20750 END IF
20760 BEEP
20770 INPUT "WANT TO PLOT ROHSENOW CORRELATION? (1=Y,0=N)",Irohs
20780 IF Irohs=1 THEN
20790 Yll=15
20800 Yul=80
20810 BEEP
20820 INPUT "ENTER Tsat (Deg C)",Tsat
20830 Csf=.0040
20840 BEEP
20850 INPUT "ENTER Csf (DEF=0.004)",Csf
20860 Tf=Tsats+2
20870 FOR Xx=0 TO Cx STEP Cx/200
20880 Xa=Xmin+10*Xx
20890 IF Xa>Xll OR Xa>Yul THEN 21170
20900 Xl=LOG(Xa)
20910 IF Opo=2 THEN Tf=Tsats+Xa/2
20920 Rho=FNRho(Tf)
20930 K=FNK(Tf)
20940 Mu=FNMu(Tf)
20950 Cp=FNCP(Tf)
20960 Hfg=FNHfg(Tsat)
20970 Nl=Mu/Rho
20980 Pr=Cp*Mu/K
20990 Omega=Csf*Hfg/Cp*((.014/(9.91+Rho))*.5/(Mu+Hfg))^(1./3)*Pr*.7
21000 IF Opo=0 THEN Ya=(Xa/Omega)**3
21010 IF Opo=1 THEN Ya=(Xa/Omega)**3/Ya
21020 IF Opo=2 THEN Ya=Xa*(2./3)/Omega
21030 IF Opo=2 THEN
21040 Tfc=Tsats+Xa/Ya*.5
21050 IF ABS(Tf-Tfc)>.01 THEN
21060 Tf=(Tf+Tfc)*.5
21070 GOTO 20920
21080 END IF
21090 END IF
21100 X=LGT(Ya/Ymin)*Sfy
21110 X=LGT(Xa/Xmin)*Sfx
21120 Ipu=0
21130 IF X>Yll THEN Ipu=1
21140 IF X>Yul THEN 21170

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21150 IF Idu=0 THEN PRINT "PA",X,Y,"PO"
21160 IF Idu=1 THEN PRINT "PA",X,Y,"PU"
21170 NEXT X
21180 PRINT "PU"
21190 END IF
21200 BEEP
21210 INPUT "WANT TO QUIT (Y=Y,N=N)";Iqt
21220 IF Iqt=1 THEN GOTO 21240
21230 GOTO 19550
21240 PRINT "PU PA 0,0 SP0"
21250 SUBEND
21260 SUB Symb(X,Y,Sym,Icl,Kj)
21270 IF Sym=3 THEN PRINT "SM"
21280 IF Sym=4 THEN PRINT "SR 1.4,2.4"
21290 Yad=0
21300 IF Kj=1 THEN Yad=-.9
21310 IF Icl=0 THEN
21320 PRINT "PA",X,Y+Yad,""
21330 ELSE
21340 PRINT "PA",X,Y+Yad,"PO"
21350 END IF
21360 IF Sym=3 THEN PRINT "SR 1.2,1.6"
21370 IF Sym=4 THEN PRINT "UC2,4,99,0,-9,-4,0,0,9,4,0;"
21380 IF Sym=5 THEN PRINT "UC3,0,99,-3,-5,-3,6,3,6,3,-6;"
21390 IF Sym=6 THEN PRINT "UC0,5,3,99,3,-9,-5,0,3,9;"
21400 IF Sym=7 THEN PRINT "UC0,-5,3,99,-3,9,6,0,-3,-9;"
21410 IF Kj=1 THEN PRINT "SM:PR 0,-.9"
21420 SUBEND
21430 SUB Purg
21440 BEEP
21450 INPUT "ENTER FILE NAME TO BE DELETED";Files
21460 PURGE Files
21470 GOTO 21440
21480 SUBEND
21490 SUB Tden
21500 COM /Ccl C(7),Ical
21510 DIM Emf(1)
21520 DATA 0.10096091,25727.94369,-767345.9295,79025595.91
21530 DATA -9247496599,6.97599E+11,-2.56192E+13,3.94079E+14
21540 READ C(*)
21550 BEEP
21560 INPUT "GIVE A NAME FOR FILE TO BE CREATED";Files
21570 BEEP
21580 INPUT "SELECT TUBE (0=WH,1=HF,2=WT)";Itt
21590 BEEP
21600 INPUT "SELECT THERMOCOUPLE TYPE (0=NEW,1=OLD)";Ical
21610 IF Itt=2 THEN GOTO 21630
21620 CREATE 90AT Files,I
21630 ASSIGN #File TO Files
21640 OUTPUT #File;Itt
21650 J=0
21660 BEEP
21670 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)";Dates
21680 OUTPUT #09;"TO":Dates
21690 OUTPUT #09;"TO"
21700 ENTER #09;Dates
21710 PRINT# 13
21720 PRINT
21730 PRINT "Month, date and time: ";Dates
21740 PRINT

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21750 PRINT USING "10X," Fms Tin Tev Uw^2 Tdrop""
21760 IF K=0 THEN
21770 PRINTER IS 701
21780 PRINT
21790 PRINT "Month, date and time: "Dates
21800 IF Itt=0 THEN PRINT USING "10X,"Tube Type: Wieland Smooth""
21810 IF Itt=1 THEN PRINT USING "10X,"Tube Type: High Flux""
21820 IF Itt=2 THEN PRINT USING "10X,"Tube Type: Turbo-8""
21830 PRINT
21840 PRINT USING "10X," Fms Tin Tev Uw^2 Tdrop""
21850 PRINTER IS 1
21860 K=1
21870 END IF
21880 BEEP
21890 INPUT "ENTER FLOWMETER READING",Fms
21900 OUTPUT 709:"AR AF0 AL4 UR1"
21910 FOR L=0 TO 4
21920 OUTPUT 709:"AS SA"
21930 IF L=0 AND L=4 THEN 22010
21940 S=0
21950 FOR I=0 TO 9
21960 ENTER 709:E
21970 S=S+E
21980 NEXT I
21990 IF L=0 THEN Enf(0)=ABS(S/10)
22000 IF L=4 THEN Enf(4)=ABS(S/10)
22010 NEXT L
22020 OUTPUT 709:"AR AF00 AL00 UR1"
22030 OUTPUT 709:"AS SA"
22040 Etp=0
22050 FOR I=0 TO 9
22060 ENTER 709:E
22070 Etp=Etp+E
22080 NEXT I
22090 Etp=Etp/10
22100 Tin=ENTvsv(Enf(1))
22110 Tev=ENTvsv(Enf(0))
22120 Grad=37.9953+.104399*Tin
22130 Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(9.92005E-6-Fms*(1.23689E-7-Fms*4.31997E-10)))
22140 Uw=Mdot/(1000*PI*Di^2)*4
22150 Tdrop=Etp+1.E+6/(10*Grad)
22160 PRINT USING "10X,3(00.00,4X),1X,2.00,4X,MZ.40":Fms,Tin,Tev,Uw^2,Tdrop
22170 BEEP
22180 INPUT "WANT TO ACCEPT THIS DATA SET? (1=Y,0=N)",Ok
22190 J=J+1
22200 IF Ok=0 THEN
22210 J=J-1
22220 GOTO 21990
22230 ELSE
22240 OUTPUT 9F:1s:Fms,Enf(1),Etp
22250 PRINTER IS 701
22260 PRINT USING "10X,3(00.00,4X),1X,2.00,4X,MZ.40":Fms,Tin,Tev,Uw^2,Tdrop
22270 PRINTER IS 1
22280 BEEP
22290 INPUT "WILL THERE BE ANOTHER DATA SET? (1=Y,0=N)",Go_on
22300 IF Go_on=1 THEN 21990
22310 END IF
22320 ASSIGN 9F:1s TO *
22330 PRINTER IS 701

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22310 PRINT
22350 PRINT USING "10X,"NOTE: "",ZZ," data sets are stored in file "",ISA";J,F
files
22360 PRINTER IS 1
22370 SUBEND
22380 SUB Uopt:
22390 PRINTER IS 1
22400 BEEP
22410 INPUT "Enter Uo File Name",File$
22420 BEEP
22430 INPUT "Number of Data Runs",Nrun
22440 INPUT "Do You Want a Plot File?(1=Y,0=N)",Iplot
22450 BEEP
22460 IF Iplot=1 THEN
22470 INPUT "Give Plot File Name",P_files$
22480 CREATE BOAT P_files,1
22490 ASSIGN @Plot TO P_files$
22500 END IF
22510 PRINTER IS 701
22520 PRINT
22530 PRINT
22540 PRINT USING "10X," Water Vel      Uo""
22550 ASSIGN @File TO File$
22560 IF Iplot=1 THEN ASSIGN @File! TO P_files$
22570 FOR I=1 TO Nrun
22580 ENTER @File:Uw,Uo
22590 IF Iplot=1 THEN OUTPUT @File!:Uw,Uo
22600 PRINT USING "15X,0.00,5X,MZ.30E":Uw,Uo
22610 NEXT I
22620 ASSIGN @File TO *
22630 ASSIGN @File! TO *
22640 PRINT USING "10X,"NOTE: "",ZZ," data sets are stored in file "",ISA";Nru
n,File$
22650 IF Iplot=1 THEN
22660 PRINT USING "10X,"NOTE: "",ZZ," X-Y Pairs are stored in file "",ISA";Nru
n,P_files$
22670 END IF
22680 PRINTER IS 1
22690 SUBEND
22700 SUB Select:
22710 COM /Idp/ Idp
22720 BEEP
22730 PRINTER IS 1
22740 PRINT USING "4X,"Select option:"
22750 PRINT USING "6X," 0 Taking data or re-processing previous data""
22760 PRINT USING "6X," 1 Plotting data on Log-Log ""
22770 PRINT USING "6X," 2 Plotting data on Linear""
22780 PRINT USING "6X," 3 Make cross-plot coefft file""
22790 PRINT USING "6X," 4 Re-circulate water""
22800 PRINT USING "6X," 5 Purge""
22810 PRINT USING "6X," 6 T-Drop correction""
22820 PRINT USING "6X," 7 Print Uo File""
22830 PRINT USING "6X," 8 Modify X-Y file""
22840 PRINT USING "6X," 9 Move""
22850 PRINT USING "6X,"10 Comb/Fixup""
22860 INPUT Idp
22870 IF Idp=0 THEN CALL Main
22880 IF Idp=1 THEN CALL Plot
22890 IF Idp=2 THEN CALL Plot
22900 IF Idp=3 THEN CALL Coef

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22910 IF Idp=1 THEN CALL Main
22920 IF Idp=5 THEN CALL Pung
22930 IF Idp=6 THEN CALL Idcn
22940 IF Idp=7 THEN CALL Usprt
22950 IF Idp=8 THEN CALL X,mod
22960 IF Idp=9 THEN CALL Move
22970 IF Idp=10 THEN CALL Comb
22980 SUBEND
22990 SUB Xymod
23000 PRINTER IS 1
23010 BEEP
23020 INPUT "ENTER FILE NAME",File9
23030 ASSIGN @File1 TO File9
23040 BEEP
23050 INPUT "ENTER NUMBER OF X-Y PAIRS",No
23060 BEEP
23070 INPUT "ENTER NEW FILE NAME",File29
23080 CREATE BOAT File29,5
23090 ASSIGN @File2 TO File29
23100 BEEP
23110 INPUT "ENTER NUMBER OF X-Y PAIRS TO BE DELETED",Ndel
23120 IF Ndel=0 THEN 23150
23130 FOR I=1 TO Ndel
23140 BEEP
23150 INPUT "ENTER DATA SET NUMBER TO BE DELETED",Nd(I)
23160 NEXT I
23170 FOR J=1 TO No
23180 ENTER @File1:X,Y
23190 FOR I=1 TO Ndel
23200 IF Nd(I)=J THEN 23240
23210 NEXT I
23220 OUTPUT @File2:X,Y
23230 PRINT J,X,Y
23240 NEXT J
23250 PRINTER IS 701
23260 ASSIGN @File1 TO *
23270 ASSIGN @File2 TO *
23280 SUBEND
23290 SUB Move
23300 FILE NAME: MOVE
23310
23320 DIM Sop(56),A(56),B(56),C(56),D(56),E(56),F(56),G(56),H(56),J(56),K(56),L(
56),M(56)
23330 DIM Tol9(56)(14),N(56),Ur(56),Ir(56)
23340 BEEP
23350 INPUT "OLD FILE TO MOVE",O2_files
23360 ASSIGN @File2 TO O2_files
23370 ENTER @File2:Nrun,Date9,Ldtc1,Ldtc2,Itt
23380 FOR I=1 TO Nrun
23390 ENTER @File2:Sop(I),Tol9(I)
23400 ENTER @File2:A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),N
(I)
23410 ENTER @File2:Ur(I),Ir(I)
23420 NEXT I
23430 ASSIGN @File2 TO *
23440 BEEP
23450 INPUT "SHIFT DISK AND HIT CONTINUE",OK
23460 BEEP
23470 INPUT "INPUT BOAT SIZE",Size
23480 CREATE BOAT O2_files,Size

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23490 ASSIGN %File1 TO D2_files
23500 OUTPUT %File1:Nrun,Date$,Ldte1,Ldte2,Itt
23510 FOR I=1 TO Nrun
23520 OUTPUT %File1:8op(I),Told$(I)
23530 OUTPUT %File1:A(I),B(I),C(I),D(I),E(I),F(I),S(I),H(I),J(I),K(I),L(I),M(I),
N(I)
23540 OUTPUT %File1:Ur(I),Ir(I)
23550 NEXT I
23560 ASSIGN %File1 TO *
23570 RENAME "TEST" TO D2_files
23580 BEEP 2000,.2
23590 BEEP 4000,.2
23600 BEEP 4000,.2
23610 PRINT "DATA FILE MOVED"
23620 SUBEND
23630 SUB Comb
23640 FILE NAME: COMB
23650
23660 DIM Emf(12)
23670 BEEP
23680 INPUT "OLD FILE TO FIXUP",D2_files
23690 ASSIGN %File2 TO D2_files
23700 D1_files="TEST"
23710 CREATE SDAT D1_files,20
23720 ASSIGN %File1 TO D1_files
23730 ENTER %File2:Nrun,Date$,Ldte1,Ldte2,Itt
23740 Nrunm=20
23750 IF K=0 THEN OUTPUT %File1:Nrunm,Date$,Ldte1,Ldte2,Itt
23760 FOR I=1 TO Nrun
23770 ENTER %File2:8op,Told$,Emf(*),Ur,Ir
23780 OUTPUT %File1:8op,Told$,Emf(*),Ur,Ir
23790 NEXT I
23800 ASSIGN %File2 TO *
23810 RENAME "TEST" TO D2_files
23820 BEEP 2000,.2
23830 BEEP 4000,.2
23840 BEEP 4000,.2
23850 BEEP
23860 INPUT "WANT TO ADD ANOTHER FILE (Y=N)?",Oka
23870 IF Oka=1 THEN
23880 K=1
23890 BEEP
23900 INPUT "GIVE NEW FILE NAME",Nfiles
23910 ASSIGN %File2 TO Nfiles
23920 GOTO 23730
23930 END IF
23940 ASSIGN %File2 TO *
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